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OF

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PROCEEDINGS.

1883.

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1883.

ERRATA IN PROCEEDINGS 1883.

Page 2, line 12, for "Romsey, Hants" *read* "Ramsey, Huntingdonshire."
" 9, " 14, for "By his invention" *read* "By the invention."
" 11, " 1, for "1881" *read* "1882."
" 14, " 22, for "Proceedings 1882" *read* "Proceedings vol. lxxi."
" 115, " 18, for "the ore" *read* "reduction of the ironstone."
" 366, " 4 from bottom, for "Lencarchez" *read* "Lencauchez."

1883.

PRESIDENT.

Percy G. B. Westmacott, ... Newcastle-on-Tyne.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
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Sir William Siemens, D.C.L., LL.D., F.R.S., . (*deceased* 1883).
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Robert Stephenson, F.R.S., ... (*deceased* 1859).

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Jeremiah Head, ... Middlesbrough.
George B. Rennie, ... London.
Francis W. Webb, ... Crewe.

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Thomas Druitt.

SECRETARY.

Walter R. Browne.

ASSISTANT SECRETARY.

Alfred Bache.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1883.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., F.R.S., Royal Arsenal, Woolwich.
1878. Crawford and Balcarres, Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; and Haigh Hall, Wigan.
1879. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.
1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.
1883. Trasenster, L., Rector of the University of Liége, 9 Quai de l'Industrie, Liége, Belgium.
1867. Tresca, Henri, Member of the Academy, &c., Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. Abbott, Thomas, Northgate Iron Works, Newark.
1883. Abbott, William Sutherland, Locomotive and Mechanical Engineer, Alagoas Railway, Maceio, Brazil.
1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, 60 Queen Victoria Street, London, E.C.

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, Messrs. Everitt Adams and Co., 35 Queen Victoria Street, London, E.C.

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester.

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.

1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good Hope: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, 6 Delahay Street, Westminster, S.W.

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1870. Alexander, Alfred, King William's Town, Cape of Good Hope: (or care of William Alexander, East Cranhams, Cirencester.)

1883. Allam, Edwin Clerk, Romford.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1881. Allen, Percy Ruskin, Anglo-American Brush Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.; and Woodberrie Hill, Loughton, Essex.

1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1882. Allen, William Milward, Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of Richard Ruffell, Talanka, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, 42 Queen Anne's Gate, Westminster, S.W.

1880. Anderson, James, Vyksounsky Iron Works, Mouram, Russia.

1856 Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.

1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, 8 Buckingham Street, Adelphi, London, W.C.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.; and 3 Whitehall Place, London, S.W.

1878. Angas, William Moore, Messrs. Wilson Brothers and Co., Alliance Works, Darlington.

1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Street, Adelphi, London, W.C.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Archer, David, Central Chambers, Corporation Street, Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons & Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Melrose, North Shore, Auckland, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, Professor of Engineering, Yorkshire College of Science, Leeds.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham; and Clive House, Shrewsbury.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow.

1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester; and 28A Market Street, Manchester. (*Life Member.*)

1881. Aspinall, John Audley Frederick, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1875. Atkinson, Edward, Messrs. Richards and Atkinson, Bank Street, Royal Exchange, Manchester; and 4 Richmond Hill, Bowdon, Cheshire. (*Life Member.*)

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester.

1879. Bagot, Alan Charles, care of Edward W. Bowles, 86 Cambridge Street, London, S.W.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley.

1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China: (or care of George Ogilvie, 110 George Street, Glasgow.)

1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1879. Baldwin, Thomas, 27 Brunswick Street, Cheetham, Manchester.

1877. Bale, Manfred Powis, 20 Budge Row, Cannon Street, London, E.C.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1882. Barber, John, 20 Park Row, Leeds.

1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.

1882. Barlow, Henry Bernoulli, Cornbrook Heald Works, Chester Road, Manchester.

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1866. Barnard, Clement, 4 Billiter Square, London, E.C.

1881. Barnett, John Davis, Mechanical Superintendent, Midland Railway, Port Hope, Ontario, Canada.

1878. Barr, James, Works Manager, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.

1883. Barras, Harry Haywood, Locomotive Superintendent, Great Western Railway of Brazil, Pernambuco, Brazil.

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Gaythorn Station, Hulme, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow; and 6 Ashwood Villas, Headingley, Leeds.

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.

1883. Bartlett, James Herbert, 148 Mansfield Street, Montreal, Canada.

1883. Bastin, Edwin Philp, Alliance Engineering Works, West Drayton, near Uxbridge.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1882. Beattie, Frank, Messrs. Morewood and Co., Woodford Iron Works, Soho, near Birmingham.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward, Dallam Forge, Warrington; and 21 Bold Street, Warrington. (*Life Member.*)

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1858. Bell, Isaac Lowthian, F.R.S., Clarence Iron Works, Middlesbrough; and Rounton Grange, Northallerton; and 16 Eaton Place, London, S.W.

1880. Bell, William Henry, Bolivia: care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W.

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.
1879. Bergeron, Charles, 2 Edinburgh Mansions, Victoria Street, Westminster, S.W.
1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.
1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.
1874. Bewick, Thomas John, Mining Engineer, Haydon Bridge, Northumberland.
1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.
1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.
1883. Bicknell, Edward, Locomotive Superintendent, La Guaira and Caracas Railway, Venezuela; and 16 Miles Road, Clifton, Bristol.
1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1875. Bisset, William Harvey, Board of Trade Surveyor, St. Katharine Dock House, London, E.; and 45 Highbury Quadrant, London, N.
1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.
1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.
1881. Blechynden, Alfred, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.
1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.
1881. Bocquet, William, Locomotive Engineer, Scinde Punjaub and Delhi Railway, Lahore, India.
1883. Bodden, George, Messrs. William Bodden and Son, Hargreaves Spindle and Flyer Works, Oldham.
1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.
1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.
1869. Borrie, John, Cranbourne Terrace, Yarm Lane, Stockton-on-Tees.
1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)
1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.
1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.
1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.

1869. Boyd, William, Wallsend Slipway and Engineering Co., Wallsend, near Newcastle-on-Tyne.

1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.

1878. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.

1881. Bradley, Thomas, Wellington Foundry, Newark.

1854. Bragge, William, Clarendon House, 59 Hall Road, Handsworth, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Works, Wednesbury.

1854. Bramwell, Sir Frederick Joseph, F.R.S., 5 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham.

1883. Bricknell, Augustus Lea, Merlin Engineering Works, Brixton Rise, London, S.W.

1881. Briggs, John Henry, Engineer, Kimberley Water Works, Kimberley, South Africa: (or care of Charles Briggs, Howden.)

1880. Bright, Thomas Smith, Picton Villa, Carmarthen.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1879. Brodie, John Shanks, Assistant to Borough and Water Engineer, Municipal Offices, Liverpool.

1852. Brogden, Henry, Hale Lodge, Altrincham, near Manchester. (*Life Member.*)

1877. Bromley, Massey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, Belvedere Road, Lambeth, London, S.E.; and 25 Ladbroke Gardens, Notting Hill, London, W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1879. Brown, Charles, Manager, Swiss Locomotive and Machine Works, Winterthur, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1881. Brown, George William, Reading Iron Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1869. Browne, Benjamin Chapman, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1869. Browne, Walter Raleigh, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, F.R.S.E., 5 Victoria Street, Westminster, S.W.

1872. Brunner, Henry, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Cliff House, Appleton, Widnes.

1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, 52 Park Street, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester.

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile.

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1877. Burgess, James Fletcher, Messrs. Ormerod Grierson and Co., 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1874. Burn, William Edward, 173 Portland Road, Newcastle-on-Tyne.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.

1882. Butler, Edmund, Kirkstall Forge, near Leeds.

1859. Butler, John, Stanningley Iron Works, near Leeds.

1877. **Campbell**, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. **Campbell**, Daniel, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1869. **Campbell**, James, Hunslet Engine Works, Leeds.

1882. **Campbell**, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1882. **Campos**, Raphael Martinez, 598 General Lavalle, Buenos Aires.

1860. **Carbutt**, Edward Hamer, M.P., 19 Hyde Park Gardens, London, W.; and Llanwern House, Monmouthshire.

1878. **Cardew**, Cornelius Edward, Locomotive and Carriage Superintendent, Nagpur and Chhattisgarh State Railway, Nagpur, Central Provinces, India: (or care of Rev. J. H. Cardew, Keynshambury House, Cheltenham.)

1875. **Cardozo**, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.) (*Life Member.*)

1878. **Carlton**, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1869. **Carpmael**, Frederick, 57 Arlingford Road, Tulse Hill Gardens, Brixton, London, S.W.

1866. **Carpmael**, William, 24 Southampton Buildings, London, W.C.

1877. **Carr**, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1874. **Carrington**, William T. H., 9 and 11 Fenchurch Avenue, London, E.C.

1877. **Carter**, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1877. **Carter**, William, Manager, Messrs. W. and J. Yates, Canal Foundry, Blackburn; and 57 Hagley Road, Edgbaston, Birmingham.

1870. **Carver**, James, Lace Machine Works, Alfred Street, Nottingham.

1883. **Cawley**, George, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1876. **Challen**, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1882. **Chapman**, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. **Chapman**, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. **Chapman**, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1883. Childe, Rowland, Mining Engineer, Stamp Office Place, Wakefield.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1882. Church, Charles Simmons, Resident Engineer, Water Works, Barranquilla, United States of Colombia; and Chacewater Vicarage, Scorrier, Cornwall.

1880. Churchward, George Dundas, Post Office, Launceston, Tasmania; and Kersney Manor, Dover.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1859. Clark, George, Southwick Engine Works, near Sunderland.

1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1878. Closson, Prosper, 48 Rue Laffitte, Paris.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.

1876. Coe, William John, 1 Rumford Place, Liverpool.

1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.

1878. Cole, John William, Elm Cottage, Osmond Terrace, Norwood, Adelaide, South Australia: (or care of Messrs. James Sinton and Co., 7 St. Benet Place, Gracechurch Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.; and 10 Hopton Road, Coventry Park, Streatham, London, S.W.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1874. Conyers, William, Invercargill, Otago, New Zealand.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, 76 Little Britain, Aldersgate Street, London, E.C.

1877. Cooper, George, Engineer and General Manager, Buenos Ayres Great Southern Railway, Buenos Ayres: (or care of Secretary, Buenos Ayres Great Southern Railway, 4 Great Winchester Street, London, E.C.)

1874. Cooper, William, Neptune Foundry, Hull.

1881. Coote, Arthur, Messrs. Andrew Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness.

1878. Cornes, Cornelius, 30 Walbrook, London, E.C.

1848. Corry, Edward, 8 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India.

1875. Cotton, Francis Michael, 9 Victoria Chambers, Victoria Street, Westminster, S.W.; and 2 Courthope Villas, Wimbledon, Surrey.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.

1868. Coulson, William, Mining Engineer, 32 Crossgate, Durham; and Shamrock House, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.

1882. Courtney, William McDougall, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1883. Crampton, George, 4 Victoria Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1883. Cropper, Henry S., Minerva Works, Alfred Street North, Nottingham.

1881. Crosland, James Foyell Lovelock, Chief Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1882. Cross, William, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1871. Crossley, William, 153 Queen Street, Glasgow.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1882. Cruickshank, William Douglass, Government Engineer Surveyor, 12 Custom House Buildings, Sydney, New South Wales.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1879. Dady, Jamsetjee Nesserwanjee, 10 Dady Sett House, Fort, Bombay, India.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's, Lancashire.

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris.

1881. D'Alton, Patrick Walter, Crohill, Angles Road, Streatham, London, S.W.

1866. Daniel, Edward Freer, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent; and 11 Needwood Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.

1879. Darling, William Littell, 87 Cromwell Road, South Kensington, London, S.W.

1878. Darwin, Horace, 66 Hills Road, Cambridge. (*Life Member.*)

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.

1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.

1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Davidson and Lees, 24 Basinghall Street, London, E.C.)

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Superintendent, Holkar and Sindia-Neemuch State Railway, Khandwa, India.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 147 Cannon Street, London, E.C.

1877. Davison, John Walter, Messrs. William and John Davison, Engineers and Ironfounders, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Pearston House, 23 The Walk, Tredegarville, Cardiff.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.

1879. Dawson, Bernard, The Laurels, Malvern Link, Malvern.

1876. Dawson, Thomas Joseph, Mining Engineer, Cocken, near Fence Houses.

1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.

1874. Deacon, George Frederick, Liverpool Corporation Water Works, Llanwddyn, near Llanfyllin, R.S.O., Montgomeryshire.

1880. Deacon, Richard William, Boeboetan, Clive Road, Penarth.

1883. Dean, Francis Winthrop, 604 Main Street, Cambridgefort, Massachusetts, United States.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.
1877. Dees, James Gibson, 36 King Street, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds.
1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C.
1882. Denny, William, F.R.S.E., Messrs. William Denny and Sons, Leven Ship Yard, Dumbarton.
1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.
1868. Derham, John J., Brookside, near Blackburn.
1883. Dick, Frank Wesley, Steel Company of Scotland, Blochairn Steel Works, Glasgow.
1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.
1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland.
1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1879. Dickson, John, Railway Wheel and Axle Works, Stourbridge.
1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester.
1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1873. Dobson, Richard Joseph Caistor, Volharding Iron Works, Soerabaya, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)
1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1868. Dodman, Alfred, Highgate Foundry, Lynn.
1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)
1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.
1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.
1879. Douglass, Sir James Nicholas, Engineer to the Trinity Board, Trinity House, London, E.C.
1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 35 Queen Victoria Street, London, E.C.

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C.

1870. Dunlop, James Wilkie, 49 Albert Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1587, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1880. Edwards, Robert, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1866. Elce, John, 9 Hopwood Avenue, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Sons, Plymouth Foundry Plymouth.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1882. Elliott, Thomas Graham, Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1870. Elsdon, Robert, 3 Poet's Corner, Westminster, S.W.; and 76 Manor Road, Upper New Cross, London, S.E.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Eyth, Max, 4 Münsterstrasse, Bonn, Germany.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, M.P., Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, Burmantofts Foundry, Leeds.

1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.

1876. Fell, John Corry, 23 Rood Lane, Fenchurch Street, London, E.C.

1877. Fenton, James, 8 Great George Street, Westminster, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.

1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India.

1881. Ferguson, William, Dunedin, Otago, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1854. Fernie, John, P.O. Box 57, Philadelphia, Pennsylvania, United States.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1865. Filliter, Edward, 16 East Parade, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C.

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Swan Village, Westbromwich.

1882. Fletcher, David Hardman, Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford.

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1883. Fletcher, George, Masson Works, Derby.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1878. Fontaine, Marc Berrier-, Ingénieur de la Marine, Toulon Dockyard, Toulon, France.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, 28 Tunnel Terrace, Newport, Monmouthshire.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 70 Whitby Street, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1882. Furrell, Edward Wyburd, London Joint Stock Bank Chambers, 124 Chancery Lane, London, W.C.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co. Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, near Saxmundham.

1882. Garrett, Richard, Messrs. Richard Garrett and Sons, Leiston Works, near Saxmundham.

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough.

1878. Geach, John Jabez, 1 South Bank Villa, New Bridge Road, Weston, near Bath.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Broad Green House, Norton, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1878. Gimson, Josiah, Welford Road Engine Works, Leicester.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.
1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.
1880. Godfrey, William Bernard, 54 Regent's Park Road, Regent's Park, London, N.W.
1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland.
1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.
1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.
1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.
1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)
1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India; and 6 Church Walk, Worthing: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)
1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E.
1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.
1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester.
1878. Grafton, Alexander, 113 Cannon Street, London, E.C.
1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 86 Osborn Road, Forest Gate, London, E.
1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.
1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.
1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.
1861. Green, Edward, Messrs. E. Green and Son, Phœnix Works, Wakefield.
1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.
1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.
1874. Greenwood, William Henry, Landore Siemens-Steel Works, Landore, R.S.O., South Wales.
1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1883. Grew, Frederick, 12 Stockleigh Road, St. Leonard's-on-Sea.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London. E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. Griffiths, John Alfred, Engineer, Waste Water Meter Co., 32 Park Lane, Liverpool; and 93 Wordsworth Street, Liverpool.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall. Road, Northampton.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Foundry and Engine Works, Blaydon-on-Tyne, R.S.O., County Durham.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby; and 39 Hartington Street, Derby.

1880. Hallett, John Harry, 120 Powell's Place, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, São Paulo, Brazil; and 91 High Street, Ashford, Kent: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1870. Hannah, Joseph Edward, Liverpool Corporation Water Works, Llansilin, near Oswestry.

1874. Harding, William Bishop, IX. Bez., Uellöerstrasse Nr. 35, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C.

1883. Hardy, John George, Vacuum Brake Co., 7 Hohenstaufengasse, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1873. Harman, Harry Jones, Chief Engineer, English and Scottish Boiler Insurance Company, 100 King Street, Manchester.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1879. Harrison, George, Chief Engineer, s.s. "Rosetta," 24 Leicester Street, Hull.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.

1883. Hart, Frederick, 16 Canning Road, Croydon.

1877. Hart, James, Borough Engineer and Surveyor, Town Hall, St. Helen's, Lancashire.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1883. Harvey, Robert, Messrs. North and Harvey, Liverpool Nitrate Works, Iquique, Chile.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C.

1881. Haslam, Alfred Seale, Union Foundry, Derby.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1878. Haughton, Thomas, 122 Cannon Street, London, E.C.

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford.

1879. Hayes, John, 27 Leadenhall Street, London, E.C.

1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.

1873. Headly, Lawrance, 1 Camden Place, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool.

1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.

1878. Hedges, Killingworth William, 25 Queen Anne's Gate, Westminster, S.W.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Woodhouse, Newton Heath Iron Works, near Manchester.

1879. Henchman, Humphrey, Cape Government Railways, Uitenhage, Cape of Good Hope: (or care of John Henchman, Uplands, Wallington, Surrey).

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China; and Gattaway, Abernethy, Newburgh, Fife.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay.

1879. Henriques, Cecil Quixam, Parliament Mansions, Westminster, S.W.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.

1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and South Bank, R.S.O., Yorkshire.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham; and 62 Blackfriars Road, London, S.E.

1870. Hodges, Petronius, 171 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.

1852. Holcroft, James, Red Hill House, Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1865. Holliday, John, Messrs. John Bethell and Co., Creosote Works, Westbromwich; and Oakfield Lodge, Booth Street, Handsworth, Birmingham.

1883. Holroyd, John, Tomlinson Street, Hulme, Manchester.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, Fairlea, Palatine Road, Didsbury, Manchester.

1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1856. Hopkinson, John, Grove House, Oxford Road, Manchester.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 18 Ann Street, Edinburgh.)

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.
1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.
1873. Hoskin, Richard, 1 East Parade, Sheffield.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.
1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire.
1882. Howard, John William, 78 Queen Victoria Street, London, E.C.
1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.
1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.
1882. Howl, Edmund, Messrs. Lee Howl Ward and Howl, Tipton.
1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W.
1882. Hudson, John George, Messrs. Mirrlees Watson and Co., 45 Scotland Street, Glasgow.
1881. Hughes, Edward William Mackenzie, Locomotive Superintendent, Indus Valley State Railway, Adamwahan, Punjaub, India: (or care of Charles William Lennox, 7, Finlayson Place, Kelvinside, N., Glasgow.)
1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.
1871. Hughes, Joseph, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven; and Moresby, near Whitehaven.
1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.
1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.
1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.
1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.
1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1865. Hyde, Major-General Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1882. Inglis, John, 14 Praya Central, Hong Kong, China.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1883. Instone, Thomas, Assistant Manager and Engineer, Elliott's Metal Works, Selly Oak, near Birmingham; and Harborne, near Birmingham.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Budapest, Hungary.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire.

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Tees Side Iron and Engine Works, Middlesbrough; and 75 Grange Road West, Middlesbrough.

1876. Jacobs, Charles Mattathias, 126 Bute Docks, Cardiff.

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne.

1870. Jamieson, John Lennox Kincaid, 9 Crown Terrace, Dowanhill, Glasgow.

1882. Jardine, John, Lace Machine Works, Raleigh Street, Nottingham.

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Jemson, James, 7 Ashton Terrace, Preston.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1878. Jensen, Peter, Messrs. Brewer and Jensen, 33 Chancery Lane, London, W.C.

1878. Jessop, Joseph, London Steam Crane and Engine Works, Leicester.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1882. Johnson, Charles Malcolm, Chief Engineer, R.N., H. M. Ironclad "Swiftsure," Esquimalt, Vancouver Island; and 11 Napier Street, Stoke, Devonport.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

1882. Jolin, Philip, Great Western Electric Light and Power Co., 16 High Street, Bristol; and Paulatim Club, 10 Adelphi Terrace, London, W.C.

1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and 2 Westhill Terrace, Chapel Allerton, Leeds.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Sakkur, near Karachi, Punjaub, India: (or care of Mrs. Edward Jones, Woodville, Wylde Green, near Birmingham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.
1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)
1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)
1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Co., Cardiff.
1880. Joy, David, 8 Victoria Chambers, Victoria Street, Westminster, S.W.; and 32 Anerley Park, Anerley, London, S.E.
1878. Jüngermann, Carl, Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, 3 Chaussée Strasse, Berlin.

1882. Keeling, Herbert Howard, Merlewood, Eltham.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1867. Kellett, John, Clayton Street, Wigan.
1873. Kelson, Frederick Colthurst, Greenbank, Waterloo, near Liverpool.
1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.
1863. Kennan, James, Messrs. Kennan and Sons, Engineering Works, Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.
1868. Kennedy, Thomas Stuart, Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds; and Meanwood, near Leeds.
1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Maple Bank, Church Road, Edgbaston, Birmingham.
1866. Kershaw, John, 1 Arlington Street, Piccadilly, London, S.W.
1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemberg, Germany.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.
1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.
1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington.
1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Imperial Maritime Customs, Chefoo, China.
1882. Kirkwood, Thomas, Harbour Engineer, Hong Kong and Whampoa Dock Co., Hong Kong, China.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1859. Kitson, James, Jun., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1874. Klein, Thorvald, Staffordshire Rolling Stock Co., Cliff Vale Wagon Works, Stoke-upon-Trent.

1875. Knight, John Henry, Weybourne House, Farnham.

1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts, West Indies: (or care of G. D. Kortright, Plas Teg, near Mold, Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1883. Lake, William Robert, 8 Southampton Buildings, London, W.C.

1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.

1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1863. Lancaster, John, Bilton Grange, Rugby.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of William G. Parsons, 11 Queen Victoria Street, London, E.C.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.

1879. Lapage, Richard Herbert, 13A Great George Street, Westminster, S.W.; and Craigleith, Paragon Road, Surbiton, Kingston-on-Thames.

1879. Larsen, Jorgen Daniel, 7 Poultry, London, E.C.; and 27 Dalhousie Square, Calcutta.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne.

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1856. Laybourne, Richard, Isca Foundry, Newport, Monmouthshire.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, 38 Bennett's Hill, Birmingham.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgefort, Massachusetts, United States.

1865. Ledger, Joseph, Keswick.

1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 1 Rue du Charolais, Paris: (or care of Messrs. Sharp Stewart and Co., Atlas Works, Manchester.)

1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn, Newcastle-on-Tyne.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1867. Lloyd, Charles, 39 Thistle Grove, South Kensington, S.W.

1871. Lloyd, Francis Henry, Darlaston Steel and Iron Works, near Wednesbury; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire; and Priors Lee Hall, near Shifnal.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1864. Lloyd, Sampson Zachary, Areley Hall, Stourport.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.
1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.
1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.
1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.
1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.
1875. Longridge, Robert Charles, Kilrie, Knutsford.
1880. Longworth, Daniel, Carnac Iron Works, Bombay.
1882. Lord, Walter, Messrs. Lord Brothers, Canal Street Works, Todmorden.
1861. Low, George, Bishop's Hill Cottage, Ipswich.
1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C.
1883. Lowe, Sutton Harvey, Eastgate House, Lincoln.
1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.
1877. Lupton, Arnold, 4 Albion Place, Leeds.
1878. Lüthy, Robert, Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.
1854. Lynde, James Gascoigne, 32 St. Ann's Street, Manchester.
1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.
1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1879. Macdonald, Augustus VanZundt, Manager, Auckland Section, New Zealand Railways, Auckland, New Zealand.
1864. Macfarlane, Walter, Saracen Foundry, Possilpark, Glasgow.
1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)
1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.
1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.
1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.; and Rotherham.

1879. **Maginnis**, James Porter, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1873. **Mair**, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1879. **Malcolm**, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1881. **Mallory**, George Benjamin, 55 Broadway, New York.

1882. **Mañé**, Marcos, Ingeniero Mecanico, Ferro Carril Oeste, Buenos Aires.

1876. **Manlove**, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. **Mansell**, Richard Christopher, Mechanical Engineer, South Eastern Railway; 24 Caversham Road, Kentish Town, London, N.W.

1875. **Mansergh**, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. **Mappin**, Frederick Thorpe, M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1882. **Mappin**, Walter Sandell, 15 Holborn Viaduct, London, E.C.

1857. **March**, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.

1878. **Marié**, George, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. **Markham**, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1871. **Marsh**, Henry William, Winterbourne, near Bristol.

1875. **Marshall**, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)

1865. **Marshall**, Francis Carr, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1871. **Marshall**, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1877. **Marshall**, William Bayley, 15 Augustus Road, Birmingham.

1847. **Marshall**, William Prime, 15 Augustus Road, Birmingham.

1859. **Marten**, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge; and Pedmore, Stourbridge.

1853. **Marten**, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. **Martin**, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. **Martin**, Henry, Hanwell, Middlesex, W.

1880. **Martin**, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1854. **Martineau**, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.
1880. Massicks, Thomas, Millom Iron Works, Millom, Cumberland.
1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.
1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China; or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.
1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.
1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)
1853. Maudslay, Henry, Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.) (*Life Member.*)
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C.
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, Calicut, Malabar Coast, India: (or care of Messrs. Leslie and Anderson, 2 Lime Street Square, London, E.C.)
1874. McClean, Frank, 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1878. McDonald, John Alexander, Aloha, Toothill Street, Petersham, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)
1865. McDonnell, Alexander, Locomotive Superintendent, North Eastern Railway, Gateshead; and Saltwell Hall, Gateshead.
1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C.
1868. McKay, Benjamin, Ice Works, Rockhampton, Queensland: (or care of Messrs. Lear Phillips and Co., 38 Dean Street, Birmingham).
1881. McKay, John, Messrs. R. and W. Hawthorn, St. Peter's Works, Newcastle-on-Tyne.
1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.
1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.
1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts United States.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1881. Meik, Charles Scott, 6 York Place, Edinburgh.

1858. Meik, Thomas, 6 York Place, Edinburgh.

1883. Melrose, James, Chief Engineer, H.M. Dockyard, Gibraltar.

1878. Menier, Henri, 37 Rue Ste. Croix de la Bretonnerie, Paris.

1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitehaven.

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1882. Molesworth, James Murray, Chinese Engineering and Mining Co., care of H. B. M. Consulate, Tientsin, China: (or care of A. Molesworth, 48 Lord Street, Rochdale.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1882. Moore, Richard St. George, Messrs. Clarke and Moore, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1872. Moorsom, Warren Maude, Linden Lodge, Clevedon.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1868. Morris, William, Waldridge Colliery, Chester-le-Street.

1865. Mosse, James Robert, General Director of Ceylon Railways; 4 Eaton Gardens, Ealing, London, W.

1858. Mountain, Charles George, Eagle Foundry, Broad Street, Birmingham.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 26 King Street, Manchester.

1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. Murdock, William Mallabey, Sun Foundry, Dewsbury Road, Leeds.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1848. Napier, John, 23 Portman Square, London, W.

1861. Naylor, John William, Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds.

1883. Neate, Percy John, Messrs. Taylor and Neate, Medway Works, Rochester.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, Broad Street, Birmingham.

1879. Neville, Robert, Butleigh Court, Glastonbury.

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. Newdigate, Albert Lewis, 25 Craven Street, Charing Cross, London, W.C. (*Life Member.*)

1881. Newman, Frederick, 5 Copthall Buildings, London, E.C.

1881. Nichol, Bryce Gray, Messrs. Donkin and Nichol, St. Andrew's Iron Works, Newcastle-on-Tyne.

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India.

1877. Nicolson, Donald, 27 Leadenhall Street, London, E.C.

1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.

1866. Norfolk, Richard, Beverley.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 125 Queen's Road, Peckham, London, S.E.

1882. Nunneley, Thomas, Messrs. Dawson and Nunneley, Black Bull Street, Hunslet, Leeds.

1868. O'Connor, Charles, Mersey Steel and Iron Works, Caryl Street, Liverpool.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C.

1880. Oldham, Robert Augustus, 17 Clarendon Road, Kensington, London, W.

1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.

1882. Olrick, Harry, 27 Leadenhall Street, London, E.C.

1882. Orange, James, Surveyor General's Department, Hong Kong, China.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1868. Paget, Arthur, Machine Works, Loughborough.

1881. Palmer, Cecil Brooke, 38 Cornhill, London, E.C.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees.

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Pershouse, 25 Exchange Buildings, Birmingham.

1881. Parry, Henry, 2 Side, Newcastle-on-Tyne.

1880. Parsons, The Hon. Charles Algernon, 7 Ashwood Terrace, Headingley, Leeds.

1878. Parsons, The Hon. Richard Clere, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1881. Pattinson, John, Locomotive Superintendent, Riazan and Kosloff Railway, Kosloff, Russia: (or care of Nathaniel Grew, Dashwood House, 9 New Broad Street, London, E.C.)

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1880. Peache, James Courthope, London and North Western Railway, Locomotive Department, Crewe.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India: (or care of William Peaker, Bretton West, Wakefield.)

1879. Pearce, George Cope, 2 St. Helen's Crescent, Swansea.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 47 Gunterstone Road, West Kensington, London, W.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1882. Perry, Alfred, Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, Post Office, Brisbane, Queensland: (or care of Messrs. Manlove Alliott Fryer and Co., Ilkeston Road, Nottingham.)

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras: (or care of Rev. E. J. Phipps, Stansfield Rectory, Clare, Suffolk.)

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France.

1882. Pirrie, John Sinclair, Messrs. Fraser and Miller, Carnac Iron Works, Bombay: (or care of Messrs. Ironside Gyles and Co., 5 Barge Yard, Bucklersbury, London, E.C.)

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia; and 27 Fernbank Road, Redland, Bristol.

1869. Player, John, Clydach Foundry, near Swansea.

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.
1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield.
1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C.
1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.
1875. Prior, Johannes Andreas, 33 Bredgade, Copenhagen.
1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.
1875. Provis, George Stanton, Whitehall Club, Parliament Street, Westminster, S.W.
1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.
1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.
1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1878. Rait, Henry Milnes, Messrs. Rait and Lindsay, Cranstonhill Foundry, Glasgow; and 155 Fenchurch Street, London, E.C.
1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1878. Ramsden, Robert, 177 Kingsland Road, London, E.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1883. Rathbone, Edgar Philip, Mining Engineer, 2 Great George Street, Westminster, S.W.
1867. Ratliffe, George, care of G. H. Horsfall, 17 James Street, Liverpool.
1862. Ravenhill, John R., 27 Courtfield Gardens, South Kensington, London, S.W.

1872. Rawlins, John, Manager, Metropolitan Railway Carriage and Wagon Works, Saltley, Birmingham.

1878. Rawlinson, Sir Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada.

1883. Reed, Alexander Henry, 90 Cannon Street, London, E.C.

1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland.

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1878. Rennie, John, care of H. T. Lannigan, 9 Laurence Pountney Lane, Cannon Street, London, E.C.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields.

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1883. Reunert, Theodore, Kimberley, South Africa; and Benson's Buildings, Park Row, Leeds.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Warda Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Stilwell, 22 Arundel Street, Strand, London, W.C.)

1882. Rhodes, Vincent, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1875. Rich, William Edmund, Engineer, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, 12 City Road, Manchester.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1881. Richardson, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1863. Rigby, Samuel, Fern Bank, Liverpool Road, Chester.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1879. Rixom, Alfred John, Woodstone Steam Brick and Tile Works, Peterborough; and 38 The Grove, Hammersmith, London, W.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Fort Gratiot, Michigan, United States.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Andrew Bruce, 46 Queen Victoria Street, London, E.C.)

1883. Robins, Edward, Assistant Engineer, Public Works Department, San Fernando, Trinidad.

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Rochdale.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, care of Messrs. Ralli Brothers, Bombay.

1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.

1868. Rogers, William, Estrada de Ferro das Alagoas (Central), Maceio, Brazil: (or care of J. Kenyon Rogers, 25 Water Street, Liverpool.)

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1867. Rose, Thomas, 14 Bank Street, Cross Street, Manchester.

1874. Ross, John Alexander George, 46 Grainger Street West, Newcastle-on-Tyne.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1860. Rumble, Thomas William, F.R.S.E., Chief Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E. (*Life Member.*)

1878. Russell, The Hon. William, George Town, Demerara, British Guiana; and 65 Holland Park, London, W.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1877. Rutter, Edward, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.

1883. Sadoine, Eugène, Société Cockerill, Seraing, Belgium.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and Royal Thames Yacht Club, 7 Albemarle Street, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1864. Samuda, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. Samuelson, Bernhard, M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Norland Works, Wharf Road, Latimer Road, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, Norwood, Lenzie, Dumbartonshire.

1881. Sandiford, Charles, Locomotive Superintendent, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.

1882. Sawyer, Frederic Henry Read, 18 Calle Real de San Miguel, Manila, Philippine Islands; and 4 Cullum Street, London, E.C.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1883. Schönheyder, William, 81 St. Stephen's Avenue, Shepherd's Bush, London, W.

1880. Schram, Richard, 9 Northumberland Street, Strand, London, W.C.

1876. Scott, David, Bengal Club, Calcutta; and Dunmuir, Newburgh, Fife.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport.

1881. Scott, George Innes, 4 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1881. Scott, James, Despatch Wool-Washing Co., Port Elizabeth, Algoa Bay, Cape Colony: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1861. Scott, Walter Henry, Park Road, East Molesey, Kingston-on-Thames.

1868. Scriven, Charles, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1882. Seabrooke, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham; and Oak Cottage, Windsor.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1881. Sennett, Richard, Admiralty, Whitehall, London, S.W.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway Carriage and Wagon Works, Saltley, Birmingham.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta; and 7 Fairholme Road, West Kensington, London, S.W.

1881. **Shanks**, William Weallens, 18 Strand Road, Howrah, Bengal.
1881. **Shapton**, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.
1863. **Sharp**, Henry, Bolton Iron and Steel Works, Bolton.
1875. **Sharp**, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.
1867. **Sharpe**, Charles James, 27 Great George Street, Westminster, S.W.
1869. **Sharrock**, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.
1882. **Sharrock**, Samuel Lord, Hydraulic Engineering Co., Chester.
1864. **Shaw**, Duncan, Mining Engineer, Cordoba, Spain.
1879. **Shaw**, Henry Selby Hele, Professor of Engineering, University College, Bristol.
1881. **Shaw**, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.
1881. **Shaw**, William, Jun., Stanners Closes Steel Works, Wolsingham, near Darlington.
1856. **Shelley**, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.
1861. **Shepherd**, John, Union Foundry, Hunslet Road, Leeds.
1875. **Sheppard**, Herbert Gurney, 89 Westbourne Terrace, Hyde Park, London, W.
1876. **Shield**, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.
1872. **Shoolbred**, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1859. **Shuttleworth**, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1851. **Siemens**, Sir William, F.R.S., D.C.L., LL.D., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Bayswater Road, London, W.
1871. **Simon**, Henry, 7 St. Peter's Square, Manchester.
1877. **Simonds**, William Turner, Messrs. J. C. Simonds and Son, Oil Mills, Boston. (*Life Member.*)
1873. **Simpson**, Alfred, 11 High Street, Hull; and Denmark House, Alexandra Road, St. John's Wood, near Hull.
1876. **Simpson**, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.
1878. **Simpson**, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1882. **Simpson**, John Harwood, Severn Tunnel Works, Portskewett, near Chepstow.
1847. **Sinclair**, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C.

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 4 Clifton Park, Clifton, Bristol.

1879. Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1876. Smith, John, Messrs. Thomas Robinson and Son, Rochdale.

1883. Smith, John Bagnold, Assistant Manager, Sheepbridge Coal and Iron Works, Chesterfield.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 10 St. Augustine's Road, Edgbaston, Birmingham.

1882. Smith, Walter Parker, 15 New Broad Street, London, E.C.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1883. Snelus, George James, West Cumberland Iron and Steel Works, Workington.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1876. Speck, Thomas Samuel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Knoll, Fulshaw Park, Wilmslow, near Manchester.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Vulcan Tube Works, Westbromwich.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1862. Stableford, William, Broadwell House, Oldbury, near Birmingham.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1880. Stafford, George, Russell Street Lace-Curtain Works, Nottingham.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.

1866. Stephens, John Classon, Messrs. Stephens and Co.. Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgmorton Street, London, E.C.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow; and 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.

1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1875. Stoker, Frederick William, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1877. Stokes, Alfred Allen, Chief Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, Bengal; and The White House, Pauntley, Newent, Gloucestershire: (or care of Messrs. W. and H. M. Goulding, 108 Patrick Street, Cork.)

1864. Stokes, James Folliott, care of Charles P. B. Shelley, 45 Parliament Street, Westminster, S.W.

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow.

1882. Sturgeon, John, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Manchester.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, London and North Western Railway, Locomotive Department, Crewe.

880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, Steel Company of Scotland, Newton, near Glasgow.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, 16 and 17 Exchange Buildings, Stephenson Place, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Superintending Engineer, Euphrates and Tigris Steam Navigation Company, Bussora and Bagdad: (or care of William Cole, 35 Grove Road, Regent's Park, London, N.W.)

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.

1874. Taylor, Arthur, Pontgibaud Lead Works, Puy de Dôme, France; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, 6 Queen Street Place, Upper Thames Street, London, E.C.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1882. Taylor, Robert Henry, Spithead Forts, Stokes Bay Works, Gosport; and Seymour Place, Stoke Road, Gosport.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1883. Taylor, William, Midland Foundry, Queen's Road, Nottingham.

1876. Taylor, William Henry Osborne, Salford Villa, 12 Elm Grove, Peckham Rye, London, S.E.

1864. Tennant, Charles, M.P., The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 19 The Parade, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.

1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.

1862. Thompson, William, 58 Fenchurch Street, London, E.C.

1879. Thomson, David, Craighead, West Heath, Belvedere, Kent.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1880. Thornbery, William Henry, Jun., Corporation Chambers, 121 Colmore Row, Birmingham.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hydraulic Engineering Works, Chester.

1882. Thornton, Hawthorn Robert, Engineer-in-Chief, Locomotive Department, Cape Government Railways, Cape Town; and 87 Wood Lane, Shepherd's Bush, London, W.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1883. Tower, Beauchamp, 19 Great George Street, Westminster, S.W.; and 27 Lillie Road, Fulham, London, S.W.

1883. Trentham, William Henry, 33 Portland Road, Notting Hill, London, W.

1876. Trevithick, Richard Francis, The Cliff, Penzance.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1883. Turnbull, Charles Henry, Mersey Dock Estate, Dock Yard, Liverpool.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 11 Little Queen Street, Westminster, S.W.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1875. Unsworth, Thomas, 79 Piccadilly, Manchester.

1878. Unwin, William Cawthorne, Professor of Engineering, Royal Indian Engineering College, Cooper's Hill, Staines.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of Walter Ross, Spencer House, Dulwich Road, Herne Hill, London, S.E.)

1880. Valon, William Andrew McIntosh, Engineer, Ramsgate Local Board, Hardres Street, Ramsgate.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.)

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1873. Waldenström, Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 12 Ash Street, Southport.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 12 Lisgar Terrace, West Kensington, London, W.

1882. Ward, Thomas Henry, Messrs. Lee Howl Ward and Howl, Tipton.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1881. Warham, Richard Landor, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.
1882. Warsop, Henry, Corporation Gas Works, Eastcroft Works, Nottingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Member.*)
1881. Watkins, Alfred, 62 South Street, Greenwich, S.E.
1862. Watkins, Richard, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.
1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.
1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.
1877. Watts, John, Broad Weir Engine Works, Bristol.
1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford.
1878. Weatherhead, Patrick Lambert, 3 Chaussée Strasse, Berlin.
1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.
1883. Weck, Friedrich, Manager, Messrs. C. and W. Walker, Midland Iron Works, Donnington, near Newport, Shropshire.
1872. Welch, Edward John Cowling, Palace Chambers, 9 Bridge Street, Westminster, S.W.
1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.
1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.
1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, A13 Exchange Buildings, Liverpool.
1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.
1877. Western, Charles Robert, Messrs. Western and Co., Chaddesden Works, Derby; and Chaddesden Hill, Derby.
1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Western and Sons, 35 Essex Street, Strand, London, W.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, 62 Dryden Street, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Jun., Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.; and 39 Great Tower Street, London, E.C.

1883. Wharton, Henry E., Engineering Manager, Basford Gas Works, Nottingham.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, Maple Street, Nottingham.

1867. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown, Wigtownshire.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and Hough House, Waterloo Road, Wolverhampton.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1874. White, Henry Watkins, 13 Barforth Road, Nunhead, London, S.E.

1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and Stancliffe, Matlock Bath; and 24 Great George Street, Westminster, S.W.

1878. Whytehead, Hugh Edward, 88 West Hill, Sydenham, London, S.E.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, 1 Park Parade, Westmorland Road, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C.

1877. Wilkinson, Robert, Fryer Concrete Co., Antigua, West Indies.

1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1883. Williams, Edward Leader, Queen's Chambers, John Dalton Street, Manchester.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 38 Parliament Street, Westminster, S.W.

1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.

1873. Williams, William Lawrence, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.

1870. Willman, Charles, Exchange Place, Middlesbrough.

1883. Willmott, Arthur Wellesley Westmacott, 11 Rue St. Joseph, Antwerp.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast.

1872. Wilson, Alfred, Messrs. Tangyes' Steel Works, Soho, near Birmingham.

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1881. Wilson, John, 9 Dean's Yard, Westminster, S.W.

1863. Wilson, John Charles, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, S.E.

1880. Wilson, Robert, 24 Poultry, London, E.C.

1883. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1867. Winby, Frederick Charles, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1872. Winstanley, Robert, Mining Engineer, 32 St. Ann's Street, Manchester.
1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.
1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C.
1871. Withy, Edward, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.
1878. Wolfe, John Edward, care of G. W. Wucherer, H.B.M. Vice-Consul, Jaragua, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)
1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Wei"; care of Chinese Customs Agency, Hong Kong, China; and 11 Grafton Street, Moss Side, Manchester.
1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China.
1882. Wolff, John Frederick, Gloucester Wagon Works, Gloucester.
1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.
1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.
1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.
1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.
1873. Woodhead, John Proctor, 54 John Dalton Street, Manchester.
1874. Worsdell, Thomas William, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.
1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.
1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.
1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester.
1881. Wrench, John Mervyn, Resident Engineer, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.
1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Messrs. Malcolm Brunker and Co., 22 St. Mary Axe, London, E.C.)
1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.
1878. Wright, George Howard, Mining Engineer, 12 Trumpington Street, Cambridge.
1876. Wright, James, Messrs. Ashmore and While, Hope Iron Works, Bowesfield, Stockton-on-Tees.

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Attercliffe, 42 Frederick Road, Edgbaston, Birmingham.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1878. Wright, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1883. Wyllie, Robert, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh.

1877. Wyvill, Frederic Christopher, 33 Obern Strasse, Bielefeld, Westphalen, Germany.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, Assistant Locomotive Superintendent, Northern Bengal State Railway, Saidpur, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1879. Yeomans, David Maitland, American Finance Co., 5 and 7 Nassau Street, New York.

1880. York, Francis Colin, care of Messrs. Hume Hermanos, Mercedes, Ferro Carril del Oeste, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York and Co., Snow Hill, Wolverhampton.)

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1881. Younger, Robert, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1880. Ziffer, Ferdinand Henry, Messrs. Ziffer and Walker, 6 Exchange Street, Manchester.

ASSOCIATES.

1880. Allen, William Edgar, Well Meadow Steel Works, Sheffield.

1880. Bagshawe, Washington, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E.

1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.

1882. Dodson, Edward, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.

1882. Drury, Robert Francis, George Street, Sheffield.

1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 9 Gracechurch Street, London, E.C.

1883. Fung Yee, Secretary, Chinese Legation, 49 Portland Place, London, W.

1865. Gössell, Otto, 41 Moorgate Street, London, E.C.

1878. Grosvenor, The Right Hon. Lord Richard De Aquila, M.P., 12 Upper Brook Street, Grosvenor Square, London, W.

1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.

1874. Hardcastle, Robert Anthony, Monk Bridge Iron Works, Leeds.

1882. Jackson, William, Kingston Cotton Mill, Hull.

1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)

1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, London, E.C.

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield.

1883. Macilraith, James, 182 Hope Street, Glasgow.

1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.

1865. Parry, David, Leeds Iron Works, Leeds.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1877. Render, Frederick, 12 St. Mary Street, Deansgate, Manchester.

1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.

1878. Roeckner, Carl Heinrich, 4 Royal Arcade, Newcastle-on-Tyne.

1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1882. Sokell, John Henry, Monk Bridge Iron Works, Leeds.

1878. Stuart, James, Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1882. Tayler, Alexander James Wallis, 63 Victoria Road, Kilburn, London, N.W.

1869. Varley, John, Leeds Forge, Leeds.

1875. Waslekar, Nanaji Narayan, 21 Old Boitokhana Bazar Road, Calcutta.

1878. Watson, Joseph, Attorney General's Chambers, New Court, Temple, London, E.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

GRADUATES.

1881. Alexander, Edward Disney, care of Rev. W. Hudson, Bishopthorpe Vicarage, York.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, 22 Portsea Place, Connaught Square, London, W.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1882. Anderson, William, North Eastern Railway, Locomotive Department, York.

1878. Appleby, Charles, Jun., Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1878. Armstrong, Joseph, Great Western Railway Works, Swindon.

1872. Armstrong, Thomas, Manor House, Didcot, R.S.O., Berkshire.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1882. Barstow, Thomas Hulme, Assistant Engineer, Locomotive Department, Auckland Railway, Auckland, New Zealand.

1881. Beesley, David Stanley, Messrs. D. S. Beesley and Co., 89 Dartmouth Street, Birmingham.

1880. Birkett, Herbert, Messrs. J. and E. Hall, Iron Works, Dartford.

1882. Blundstone, Samuel Richardson, 5 Clarence Villas, Moore Park Road, Walham Green, London, S.W.

1883. Booth, William Stanway, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1882. Bowles, Edward Wingfield, Messrs. Apps and Bagot, 433 Strand, London, W.C.

1878. Brooke, Arthur, Clifton Down, Stamford Hill, London, N.

1880. Buckle, William Harry Ray, 18 Bootham, York.

1878. Buddicom, Harry William, Moreton Villa, Abergavenny.

1879. Burnet, Lindsay, Messrs. John Norman and Co., Keppoch Hill Engine Works, 475 New Keppoch Hill Road, Glasgow.

1883. Cairns, The Hon. Herbert John, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. Clench, Frederick McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1881. Clench, Gordon McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Clinkskill, Alfred Alphonse Rouff, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1883. Cotton, Henry Streatfeild, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and 1 c Vincent Square, Westminster, S.W.

1883. Cowan, Henry John Franklin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Cumming, Robert, 23 Thompson Street, Govan, Glasgow.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Brown and Adams, Guild Hall Chambers, Cardiff.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1883. Gibbons, Charles Kenrick, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1882. Hart, Norman, care of Messrs. Monteiro Hime and Co., Rio de Janeiro, Brazil: (or care of Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.)

1882. Heath, Ashton Marler, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham.

1874. Hedley, Henry, Coppa Colliery, near Mold, Flintshire.

1874. Hedley, Thomas, 49 Church Road, Stanley, Liverpool.

1883. Henderson, William, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1883. Hill, John Kershaw, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Jenkins, Rhys, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1883. Lander, Philip Vincent, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1881. Lawson, James Ibbs, New Zealand Railways, Dunedin, Otago, New Zealand.

1881. Lockyer, Norman Joseph, Manchester Sheffield and Lincolnshire Railway, Locomotive Department, Gorton, Manchester.

1879. Lowthian, George, 3 Victoria Mansions, Victoria Street, Westminster, S.W.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow.

1883. Malan, Ernest de Mérindol, District Railway Works, West Brompton, London, S.W.

1878. Mannock, Thomas, Messrs. Higginbottom and Mannock, Crown Iron Works, Hyde Road, West Gorton, Manchester.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1883. Marrack, Philip, R.N., Royal Naval College, Greenwich, S.E.

1882. Martindale, Warine Ben Hay, 21 Kensington Gardens Square, London, W.

1882. Maw, Matthew Henry, Assistant Engineer, Public Works Department, India; 22 Station Road, South Norwood, London, S.E.

1882. McLaren, Raynes Lauder, 14 Royal Parade, Blackheath, London, S.E.

1881. Milles, Robert Sydney, St. Margaret's, Staplehurst.

1867. Mitchell, John, Swaithe Colliery, Barnsley.

1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1872. Napier, Robert Twentyman, Yoker, Dumbartonshire.

1878. Newall, John Walker, Forest Hall, Ongar, Essex.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1881. Norris, Moraston Ormerod, Assistant Engineer, Public Works Department, Madras: care of Messrs. Arbuthnot and Co., Madras.

1883. O'Connor, John Frederick, 16 Exchange Place, New York.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, Frankton House, Oswestry.

1883. Palchoudhuri, Bipradas, 35 Wellington Street, Calcutta.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1879. Phillips, Robert Edward, Rochelle, Selhurst Road, South Norwood London, S.E.

1883. Pigott, Arthur Walter, Messrs. Black Hawthorn and Co., Gateshead.

1881. Rogers, Philip Powys, Assistant Engineer, Warda Coal State Railway, Warora, Central Provinces, India.

1882. Sanchez, Juan Emilio, care of Mateo Clark, 4 St. Mary Axe, London, E.C

1882. Scott, Charles Herbert, Montataine Steel and Iron Co., Pagny-sur-Meuse, France.

1881. Scott, Ernest, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1883. Simpson, Charles Liddell, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne.

1879. Solly, Arthur John, Heathfield, Congleton.

1877. Spielmann, Marion Harry, 16 Porchester Terrace, Hyde Park, London, W.

1883. Spooner, Henry John, Messrs. Clark and Standfield, 6 Westminster Chambers, Victoria Street, Westminster, S.W.

1883. Swale, Gerald, Anglo-Austrian Brush Electrical Co., Vienna.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1875. Walker, Arthur Henry, Guild Hall Chambers, Cardiff.

1881. Walkinshaw, Frank, Hartley Grange, Winchfield.

1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, 10 Garlinge Road, Cricklewood, London, N.W.

1879. Wood, Edward Walter Naylor, 7 Theresa Terrace, Hammersmith, London, W.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.; and 27 Alma Road, St. Paul's Road, Canonbury, London, N.

1882. Woollcombe, Reginald, Assistant Engineer, Public Works Department, India; care of Messrs. King King and Co., Bombay.

Institution of Mechanical Engineers.

MEMOIRS

OF MEMBERS DECEASED IN 1882.

Thomas Adams was born on 3rd March 1826 at Dalmeny, a small village near Linlithgow in Scotland; and died very suddenly at Sandown, Isle of Wight, on 9th April 1882, at the age of fifty-six. He worked for many years as a workman in locomotive shops; and also had a varied experience in marine work, gained at different marine engineering establishments in the country. His first venture in business was the introduction of a balanced slide-valve, which was applied in great numbers to locomotive and winding engines, and also to several ships of the English and French navies. Through some cause the business did not prosper financially, and Mr. Adams eventually found himself once more a poor man. About 1873 however he brought out a new spring Safety-Valve. It was freely prophesied that this valve could not possibly work owing to the increasing resistance of the spring as the valve lifted. How fallacious was this view of the question may be inferred from the fact that over 20,000 "Adams" valves are working at the present moment. Mr. Adams started the Ant and Bee Works, West Gorton, Manchester, for their manufacture, and was actively engaged to the day of his death with the various details of the business. He became a Member of the Institution in 1875, and was a Member of the Institution of Naval Architects, and of the Institution of Engineers and Shipbuilders in Scotland.

Charles Edwards Amos was born on 27th November 1805, at March, in the Isle of Ely, Cambridgeshire. Soon after his birth his parents settled in Wildmore Fen, Lincolnshire, but he was left with his grandfather, Mr. Edward Sharpe, millwright and carpenter,

at March. His early years were spent mainly in agricultural employment, but at the age of about eighteen years he apprenticed himself to Mr. John Wilkinson, millwright and machine-maker of Elm. Starting on a weekly wage of 10*s.* 6*d.*, with which he had to maintain himself, he soon became so far useful to his master as "leading-hand" on out-door work as to be frequently placed in charge of such jobs; and remained about four years, during which he acquired a competent knowledge of windmills, sluice work, threshing machines, and other mechanism incidental to a country business. When twenty-two years of age and an experienced journeyman, he found employment at the workshop of Mr. Beaumont, of Romsey, Hants, whose practice was almost exclusively confined to fen work, *i.e.* the construction and repair of windmills, scoop-wheels, sluices, &c. Being anxious to see some different class of work, he went into the shop of Mr. John Clark, millwright, of Houghton, Huntingdonshire, where, in the practical construction of corn mills, water-wheels, windmills, and tannery and brewery work, abundant field for experience was found. About the year 1829 he entered the employment of Mr. Joseph Jordan, millwright, of Hertingfordbury, Herts, whose practice was of a similar character to Mr. Clark's, and who was executing some work on steam engines and other machinery for Mr. Thomas Creswick, of Hatfield Paper Mills. Mr. Amos was sent to erect and start it. Mr. Creswick was one of the most active and enterprising paper-makers of the day; and wishing to introduce several new improvements and processes into his manufactory and machinery, and to keep them private for trade purposes, he was anxious to have a steady and skilful constant hand exclusively to himself. He offered Mr. Amos this situation, which (after consulting Mr. Jordan and obtaining his approval) he accepted, and gradually he became Mr. Creswick's engineer, and was consulted by him in all concerning the machinery of the mill.

In the autumn of 1835 Mr. Creswick purchased the property known as the Iron Mills, Wandsworth, Surrey, which had been a rolling mill and foundry. The forming of a paper mill, and adaptation of the old iron mills for the purpose, and the removal of the machinery from the Hatfield Mills, became an important

matter, which was entrusted by Mr. Creswick to Mr. Amos, on condition that the latter should remain in his employment until the completion of the work. In consequence he removed to Wandsworth, his last employment before leaving Hatfield being the examination and putting in order of the fire-engines, plant, and fire appliances of Hatfield House, immediately after the fire which partly destroyed that mansion. At Wandsworth the paper-mills work was placed in the hands of Mr. H. Pullen, engineer, who had also a contract with Mr. George Dives for a new steam-engine &c. at his mills in Battersea; and on the sudden death of Mr. Pullen, Mr. Amos undertook the completion of both these contracts.

Although the advantages of expansion in the working of steam engines were known, not much practical use was made of the knowledge. The general principle of the "Woolf" or compound engine had been set forth about 1804; but very little practical use had been made of it, and its employment in the presence of the then existing practice was attended with some hardihood. Nevertheless a compound beam-engine was erected at Mr. Dives', the details of which were worked out by Mr. Amos; and the economical effect was, at the time, remarkable. The engine in question is (or was up to a short time since) still at work, and its performance bore respectable comparison with the engine-duties of the present day. Its success attracted a good deal of attention at the time, and among other persons who through it came in contact with Mr. Amos was the late Mr. James Easton; the acquaintance resulted in a partnership, which commenced in 1836, as millwrights, engineers, and lead-pipe manufacturers, at the Old Grove Works, Southwark.

The compound engine, on the system employed at Mr. Dives' mill, became a speciality in the hands of Easton and Amos. Soon after the establishment of the firm, the remodelling of Mr. Walker's Oil Mills at Dover was placed in their hands. For driving some of the machinery a pair of side-lever marine engines from one of the old packets, the "Royal George," was employed. Mr. Amos removed the cylinder of one, and compounded it with the other engine by putting in a smaller cylinder in its place. As the cranks were at right angles, the disused cylinder was placed between the

engines as an equaliser. This succeeding, another pair of marine engines was similarly employed, the equaliser being dispensed with; but no important difference in working was observable. This is probably one of the oldest instances on record of compounding marine engines. In another case, near Battersea, Mr. Amos employed two steam engines, the one a high- the other a low-pressure engine, using a spare boiler as the intermediate vessel, and keeping just so much fire beneath it as made good the loss by condensation &c. Although a novelty in its way, the arrangement answered very fairly.

His old experience of paper-making was also turned to account, and several of the principal mills of the country were either built, remodelled, or added to under his auspices. In 1849 he took out patents for a new knotter or pulp-strainer, also for a single-sheet cutting machine, which rapidly found favour both in the English and Continental paper mills; and a further patent for an automatic regulating valve, for giving steam of constant tension, notwithstanding variations of boiler pressure.

While advocating strongly the merits of compound engines, he was not insensible to the claims of single-cylinder expansion. He always stated that he believed he was the first man who successfully applied a cut-off slide, working direct on the back of an ordinary slide, for expansive working; and there are good grounds for supposing he was correct in this belief. The supplying of towns with waterworks machinery became a special object of attention, and a large practice resulted. One of the consequences of this, mechanically speaking, was the revival of the use of the "bucket-and-plunger" or "double-acting pump."

The construction of the Conway and Britannia Tubular Bridges in 1846–50, by Mr. Robert Stephenson, was the means of placing the designing and arrangement of the hydraulic machinery for the raising of the tubes of these structures in the hands of the firm, and preserved for them, and for Mr. Amos himself, the favourable opinion of Mr. Stephenson. It was probably partly due to Mr. Stephenson's recommendation that the firm became, on the retirement of Mr. Josiah Parkes, consulting engineers to the Royal Agricultural Society of England. At the Norwich Show in 1849

Mr. Amos established the system of engine trials on the "Prony" brake, which has largely contributed to the high duty and general excellence of the modern portable engine. The invention of a dynamometer, whereby the actual dynamic effort involved in working any winch-driven implement was recorded by automatic lever and spring-balance movements, was the means of securing special recognition and a special gold medal from the Society in 1849. An apparatus for ascertaining the power consumed by horse-gear threshing machines was brought into use at the Exeter Show in 1850; and a rotary dynamometer, whereby the power consumed by any machine driven by steam or other prime motor was recorded, was invented and brought into use at the Lincoln Show in 1854. Many further improvements in the testing arrangements of the Society were afterwards carried out under Mr. Amos's superintendence, up to the time of his retirement in 1870.

The arrangement and construction of the cable-laying machinery, for the old Atlantic cable in 1857, was entrusted to the firm; and Mr. Amos suggested the placing of the paying-out drums in duplicate, so as to form a self-fleeting windlass—a device he had employed some years before with success at the Rhyl swivel bridges, on the Chester and Holyhead Railway. The merit of the "dynamometer" arrangement, which was brought out and designed for this expedition, is also entirely due to Mr. Amos. This system has become of almost universal use in succeeding submarine telegraph expeditions. Mr. Amos assisted as a volunteer on board the "Agamemnon," in the experimental cruise which Sir C. Bright conducted in the Bay of Biscay, prior to the sailing of the expedition across the Atlantic.

About the same date Mr. Amos was concerned in the arrangement and construction of the hydraulic machinery for raising the tubes of the Royal Albert Bridge at Saltash, under Mr. Brunel.

The invention of Appold's centrifugal pump was the means of establishing a lasting friendship between the late Mr. J. G. Appold, F.R.S., and Mr. Amos. He bestowed much time and thought on the investigation of the general laws governing the action of such pumps, and in experimenting upon them under varying conditions.

He gave especial attention to their larger applications, *e.g.* to the pump constructed for the reclamation and permanent drainage of the Whittlesea Mere, which was 4 ft. 6 in. diameter, and delivered about 100 tons of water per minute, at from 4 to 5 ft. lift. Although machinery of far greater magnitude has been constructed since, it remains probably as successful an example as exists, and works as efficiently as it did in 1852.

He also brought out a design whereby the pump, engines, gearing, and all appurtenances were brought together in a self-contained form, and carried by one large circular cistern of iron. The fan was laid horizontally, with a vertical shaft supported from above, so that in case of repair all the working parts could be removed even when under water, and replaced similarly. The system was very successful, and was largely adopted for the West India sugar estates, reclamations in Holland, and fen drainage purposes; also for graving docks, as at H.M. Dockyard at Portsmouth, and elsewhere. In the erection of the lift, invented by Mr. Edwin Clark, at the Thames Graving Dock, Victoria Dock, the hydraulic arrangements were placed in the hands of the firm; and Mr. Amos introduced a three-cylinder compound engine, and a system of working the hydraulic pumps in groups, throwing off in succession as the lift proceeded and the stress increased. Many other improvements, as in slate-dressing, lead-pipe making, &c., were due to him; and even after his retirement in 1866 he was not idle, holding the chairmanship of the Sutton Gas Works, and a directorship of the Grays Chalk Quarries, and engaging also in other industrial pursuits. He found leisure to design and construct, at the request of the Society of Arts, a special dynamometer for testing the tractive force required on various pavements in London with a given load, and to arrange a course of experiments thereon.

Mr. Amos became a Member of the Institution in 1861, and a Member of Council in 1868. He was also a Member of Council of the Royal Agricultural Society of England from 1858 to 1882. He officiated as British juror at the Paris Universal Exhibition of 1855, and at the London Universal Exhibition of 1862. He attended, by invitation, the Universal Agricultural Exhibition of

Sweden and Norway, held at Gothenburg in 1871, when he was presented with a gold medal and diploma, and also received from Carl XV., the then reigning sovereign, the Cross of the Order of Vasa. A severe attack of illness in the winter of 1881 effectually undermined his naturally strong constitution, and on 12th August 1882 he expired at his home at Clapham, apparently without pain or pang of any kind, in the seventy-seventh year of his age.

THOMAS AVELING, of Rochester, was born on 11th September 1824, at the village of Elm near Wisbeach, Cambridgeshire, in which county his family had lived for many generations, and where his grandfather was High Sheriff in 1802.

Mr. Aveling's first occupation was farming, which he followed under the late Mr. Robert Lake, of Milton Chapel near Canterbury. Whilst so engaged he was brought face to face with the fact that the few agricultural implements of that date—some forty years ago—were crude in design and often bad in workmanship; the corn drill, the reaper, and the horse threshing-machine were in their infancy, and the steam plough had yet to be invented. In all the implements then in use on Mr. Lake's farm he took the liveliest interest; and possessing a natural bent for mechanics and a remarkable faculty for understanding at once what would work and what would not, he was able, in effecting repairs, to make improvements at the same time. At about twenty-five years of age he took a farm on his own account at Ruckinge on Romney Marsh, and on this farm he placed one of the earliest portable engines and threshing machines made by Messrs. Clayton and Shuttleworth. With the construction and working of the engine he soon became quite familiar, effecting all minor repairs and adjustments with his own hands; and in the early days of portable-engine construction, in out-of-the-way districts such as Romney Marsh then was, such repairs might well tax the ingenuity of a practical engineer. Whilst using this engine on his own farm and hiring it out to neighbours, he was struck with the mechanical absurdity, now generally admitted, of allowing so ponderous and at the same time so powerful a machine to be drawn by four horses, when it possessed in itself a power ten

times that of the horses which, with more or less risk of serious injury to themselves, were laboriously dragging it. In 1856 Mr. Aveling introduced the steam plough into Kent, in conjunction with the late Mr. John Fowler of Leeds and Messrs. Ransomes and Sims of Ipswich. This so well pleased some of the leading agriculturists of the county that a handsome testimonial and a purse of 300 guineas were presented to him. At this time a small millwrighting and foundry business was for sale at Rochester. This Mr. Aveling and his father-in-law, Mr. Lake, bought; and here Mr. Aveling (besides carrying on the former business) developed a considerable trade in the repair of portable engines, and in the conversion of new portable engines into self-moving engines by the substitution of a revolving road-shaft for the ordinary axle, wider and stronger wheels, and the addition of a pitch-chain to transmit the power from the crank-shaft. The earlier engines were without steering gear, a single horse in shafts serving to steer them. The first patent for pitch-chain driving-gear was taken out in 1859, the object being to take up the slack due to the wear of the chain, without affecting the pitch-line of the gearing. This object his invention effected in a simple manner; and it is not too much to say that the great success his engines met with from the first was due to the faith he had in pitch-chains, which are more suited for the rough usage and crude repairs of country districts than cast-iron geared wheels. In 1860 he exhibited for the first time a self-moving engine at the Royal Agricultural Society's Show at Canterbury; and in 1861, at the Leeds Show of the Society, he exhibited for the first time an engine entirely of his own manufacture. It was at this period that he was joined by Mr. Porter, who, with Mr. Aveling's only son, Mr. Thomas Lake Aveling, is now carrying on the business at Rochester. By this partnership, which was only terminated by Mr. Aveling's death, a thorough commercial knowledge was added to Mr. Aveling's practical abilities, thus contributing largely to the success and repute of the Rochester firm. From the date of the construction of Mr. Aveling's first self-moving engine he always aimed at simplicity and strength. He never put two cylinders where one would do. By placing the crank-shaft aft, and the cylinder forward, he secured two advantages: first,

dry steam when most wanted, *i.e.* when pulling up hill; and secondly, the fly-wheel within reach of the driver, should he carelessly let the crank stop on the centre.

Seeing that one of the most important elements of success in road locomotives was a supply of dry steam to the cylinder, he arranged a steam-jacket in such a way as to serve for a dome; and in later years he substituted wrought-iron brackets (formed by continuing upwards and backwards the side plates of the firebox) for the cumbrous cast-iron brackets previously in use, thereby greatly increasing the strength of the engines and their immunity from breakdowns. It is this rigid adherence to simplicity and strength which entitles him justly to be called the "father of traction engines," as George Stephenson was of locomotives.

By his invention and introduction of steam road-rollers, the condition of the macadamised roads of our towns has been entirely altered, and an economy of from one-fourth to one-third in material has been effected, whilst the saving in wheel-tyres, horse-shoes, horse-flesh, and time cannot be computed. He was one of the first men in this country to see the importance of hydraulic riveting; he put down one of Tweddell's riveters at Rochester in the spring of 1872, and the hydraulic plant there is now very complete, comprising fixed and portable riveters, shearing and punching machines, and hydraulic cranes.

Mr. Aveling demonstrated that on *dry* land it was possible to plough by direct traction, though the system cannot compete successfully with wire-rope traction, so large a portion of the power being absorbed in propelling the engine itself. Experiments on the same principle with a reaping machine were more successful; and by attaching a large side-delivery Bell-Crosskill reaper to one of his crane engines, pushing it in front, lifting it off the ground by the crane at the turns, and driving the cutter-bar by a pitch-chain from the crank-shaft, a most successful machine was made, which took a Gold Medal at the Royal Agricultural Society's Show in 1876. Previously to the introduction of the present worm-wheel and chain-barrel steering-gear, Mr. Aveling invented an ingenious and simple appliance which gave very good results for

many years; and as it is now nearly extinct it will be interesting to record it here. By this arrangement the leading axle of the engine had attached to it a triangular frame projecting forwards, and carrying at its front end the vertical axis of a forked spindle, in the fork of which was mounted a sharp-edged wheel bearing on the road. This pilot wheel could be readily diverted by a tiller carrying a quadrant with handles at intervals; and when thus diverted it carried round the front end of the light frame, and thus led round the leading axle which was compelled to follow the pilot wheel.

Mr. Aveling was also concerned in the introduction of steam for purposes of war; his "steam sappers" are well known in the Artillery and Royal Engineers, and have rendered important service in recent campaigns.

By the combination of a traction engine with a jib and chain-barrel a most effective crane-engine was constructed by Mr. Aveling, and exhibited at Bedford in 1868, and in 1870 at Oxford. Engines capable of lifting six tons and moving with that load have been made on this principle. At Agricultural Shows and International Exhibitions they have proved invaluable, notably at Vienna in 1873, and at Paris in 1878. It was probably largely due to the honorary work performed by the engine at Vienna in 1873 that Mr. Aveling received from the Emperor of Austria the Order of Franz Joseph, and after the Paris Exhibition, from the French Republic, the Legion of Honour.

Mr. Aveling was a Member of the Institution of Civil Engineers; and was elected a Member of the Council of the Royal Agricultural Society in 1875. Here his energy and ability were much felt in all things relating to showyard contracts and other matters involving technical knowledge. He became a Member of this Institution in 1869. He was an active member of the Farmers' Club and of the Society of Agricultural Engineers. In the town of his adoption, to the prosperity of which he so largely contributed, he took the most lively interest in public affairs, more especially in all matters connected with education and rational recreation. The opening of the Corn Exchange, the Castle Gardens, Public Baths, &c., are all due to him. He died from congestion of the lungs, caught whilst

yachting, on Tuesday, 7th March 1881, at the comparatively early age of fifty-seven. A memorial fund to his memory has been set on foot in Rochester, with the object of founding an "Aveling scholarship" at Sir Joseph Williamson's School.

Capt. CARLOS BRACONNOT was born of French parents, at Rio Janeiro, and entered the naval school there in 1846. He served in the River Plate campaign against the Argentine Dictator Rosas, and distinguished himself in the naval action at Tonalero. While first lieutenant he was sent by the naval department to England to study marine engineering, and remained for some time in the works of Messrs. John Penn and Sons. On returning to Brazil in 1856 he was appointed assistant engineer to the imperial marine arsenal, and subsequently engineer-in-chief and director of the workshops belonging to the naval department. Here he greatly distinguished himself by his exertions during the war with Paraguay, 1864 to 1870, when, in conjunction with Captain Level, director of the ship-yard, he fitted out three armour-clad corvettes and six monitors in less than two years. In 1872 he formed one of the commission entrusted with the construction in England of the iron-clad frigate "Independencia." Shortly afterwards ill health compelled him to resign his appointment, and he retired to Paris, where he died on 13th October 1882. He was Chevalier of the Legion of Honour, and had several Brazilian orders. He became a Member of the Institution in 1875.

ROBERT BRIGGS was born on 18th June 1822, in Boston, Massachusetts, and was educated in the public schools of that city. At the age of seventeen he entered the office of Captain Alexander Parris, a civil engineer and architect of Boston and Charlestown. Here he remained for several years, partly in the capacity of pupil and partly in that of assistant, his experience including nearly all of the more important branches of work which are usually comprehended in the duties of both the civil and the mechanical engineer.

Leaving Boston in 1844, Mr. Briggs followed other pursuits for a time; but in 1847 he returned there, and after a few months'

work under Mr. Charles Hastings, C.E., in laying out a line of railway in Massachusetts, he accepted a position as "constructing engineer" to the Glendon Rolling Mill, a large and important establishment then being built at East Boston. Upon the completion of that work he opened an office of his own in Boston as architect and engineer, an experiment which met with but small success. In August 1848 he entered the service of Walworth and Nason, of Boston, and assumed the charge of the building of their tube works, and the superintendence of the same when completed.

In the latter part of 1852 he accepted the position of superintending engineer of the firm of Bird and Weld (now the Phœnix Works) of Trenton, New Jersey, where he was employed in the construction of machinery for the manufacture of rubber and other miscellaneous purposes. Leaving here in November 1853, he was for some time engaged as a manager of rolling mills; but in 1855 he accepted an appointment as assistant engineer under Captain (now General) M. C. Meigs. In this capacity he was employed at first in the building of the Washington Aqueduct, and subsequently in the erection of the ironwork forming the dome of the Capitol at Washington, and in the heating and ventilation of the halls of Congress. During his connection with these important works, he conducted an original investigation into the strength and proportions of cast-iron pipes; and in connection with the heating and ventilation of this building, made the elaborate and original researches which were subsequently embodied in a paper read in 1870 before the Institution of Civil Engineers, on "The Conditions and the Limits which govern the proportions of Rotary Fans" (Proceedings, vol. xxx., p. 276).

In 1858 he became, for one year, a partner in the firm of Nason Dodge and Briggs, of New York. The senior partner in this firm, Mr. Joseph Nason, was a pioneer in the art of heating buildings by steam; and in this new association Mr. Briggs enlarged the experience he had already gained while in the employ of Walworth and Nason, as a designer and constructor of appliances for heating by steam, including the manufacture of all kinds of brass and iron fittings for the same.

Coming to Philadelphia in 1860, he became superintendent and engineer of the Pascal Iron Works of Morris Tasker and Co. These works, under his management, became the largest American producers of wrought-iron pipes and boiler flues, of iron and brass fittings and valves, of machinery for cutting and screwing pipes, of appliances for steam and hot-water heating, and of apparatus for gas works. In 1862–63 he designed and erected large additional buildings for the Pascal Works, including a new pipe-mill and machine-shop, which proved convenient and economical, and far better than any similar plant previously erected. About this time he also designed and constructed for Galveston, Texas, a flat-top gas-holder, built without interior trussing. It is believed that this method was original with Mr. Briggs. Among the improvements introduced by him in the manufacture of tools for pipe-fittings, was the application of the Blanchard lathe to tap-making, by which the "backing-off" of taps was done by machinery, instead of by the laborious hand-process previously in use.

In January 1866 Mr. Briggs visited England on behalf of the Pascal Iron Works, chiefly to examine the Siemens Regenerative Furnace, with a view to applying it for heating plates in tube-making. At the conclusion of his connection with the Pascal Iron Works, in November 1869, he again visited England, where he remained nearly a year, enlarging his acquaintance with English engineers, and continuing his study of their practice, particularly in connection with tube-making.

Returning to the United States he became, in January 1871, the superintendent and engineer of the Southwark Foundry, then belonging to Mr. Henry G. Morris. During this connection he designed and built a pumping engine for Lowell, Massachusetts, which may be regarded as the largest single work of his life. It was a compound rotative engine of the "Simpson" type, with a capacity of five million gallons per twenty-four hours under a head of 160 feet. When completed it gave a duty of over one hundred millions. He also designed and constructed a large variety of heavy work, including sugar mills and sugar-refining machinery, gas apparatus, blast-furnace engines and furnaces, stationary engines,

nitrate of soda apparatus, &c. His engagement lasted until the closing of the works in 1875, when he again made a short visit to England. In 1876 he became the editor of the Journal of the Franklin Institute, which position he filled for several years. In 1878 he opened an office in Philadelphia as consulting engineer; and in 1880 he became consulting assistant to Colonel Ludlow, United States engineer of river and harbour improvements in the vicinity of Philadelphia. The terms of his engagement permitted him to retain a portion of his office practice, and he continued, until his final illness, to give more or less attention to miscellaneous engineering affairs, including particularly the heating and ventilating of large buildings. One of his papers, read before the American Society of Civil Engineers, of which he was a Member, on the "Ventilation of Halls of Audience," attracted much attention. In it he urged that American engineers should discard European practice in this branch, as unsuited to the conditions both of climate and physical constitution of the population; and he referred to the well-authenticated fact that the modern American requires a temperature of not less than 70° F. for comfort, although Englishmen are comfortable in a room at 60°. In 1882 he presented to the Institution of Civil Engineers an elaborate paper on "American practice in Warming Buildings by Steam" (Proceedings 1882, p. 95). Early in 1882, after his return from a last brief visit to England, indications of paralysis developed themselves. In the spring he left Philadelphia, and went to his mother's home in Dedham, Massachusetts, where he died on 24th July 1882, having just completed his sixtieth year.

Mr. Briggs' contributions to the literature of engineering were very numerous and valuable. Among them may be mentioned, in addition to the papers above referred to, his article on the "Transmission of Force by Belts and Pulleys," based on the experiments of Mr. Henry R. Towne, usually known as "Briggs' and Towne's experiments," which have been adopted in the text-books both of America and of England; a report on the "Ventilation of the House of Representatives, Washington;" a paper on the "Circulation of Water in Steam Boilers," &c. He became a Member of the Institution in 1882.

DAVID CAMPBELL was born in Glasgow on 24th September 1813, and was educated there. He served his apprenticeship as an engineer and millwright, first at Lennox Mill, Campsie, and afterwards with Messrs. Murdoch and Aitken, of Hill Street Foundry and Engine Works, Glasgow. Shortly after finishing his time he removed to Lancashire, where he was employed by Messrs. Hick Hargreaves and Co., Bolton, and Messrs. George Forrester and Co., Vauxhall Foundry, Liverpool. In 1839 he was sent out by the latter firm to Russia, to take charge of the fitting up of some machinery; and shortly after his return, about the beginning of 1843, he was sent out to India in charge of some new presses for the Coloba Press Co. of Bombay. On the completion of this engagement he was re-engaged by the same company as their resident superintendent engineer, which position he held for some fifteen years. During this time he did much in the way of improving machinery for pressing cotton and other goods, and brought out several inventions in connection with screw and side-lever presses. Even after his return from India in 1857, he was still retained for several years in the service of the company as their consulting and inspecting engineer in England. In the autumn of 1871 he was induced to go out to India again; but finding the climate rather trying at his advanced age, he made only a short stay. After his return he carried on business as a consulting and inspecting engineer, first in Liverpool and Glasgow, and subsequently in Glasgow only. He held the appointment of inspector of new pipes for the Liverpool Corporation Water Works up to the time of his death, which took place at Glasgow on 11th May 1882, from congestion of the lungs. He was also representative in Scotland of Messrs. Sharp Stewart and Co., and of the Bolton Iron and Steel Co.; and in the latter capacity is believed to have been the first to introduce Bessemer steel to the Clyde shipbuilders and the railway engineers around Glasgow. He became a Member of the Institution in 1864.

FREDERICK COOPER was born on 11th April 1836 in Salford, and was apprenticed in 1851 at the works of Messrs. William Muir and Co., toolmakers, Manchester, completing his articles in 1857. He

was engaged at Sheerness Dockyard until 1859, when he returned to Messrs. Muir, and worked as under-foreman until 1860. Mr. William Muir being then applied to by the officials at the India Office for some good mechanic, to act as foreman in India, selected Mr. Cooper; who proceeded to Bombay in 1860, and started as foreman in the Royal Gun Carriage Department, Bombay. He was raised to the rank of chief foreman after a few years, and ultimately became manager, continuing in that position until his decease on 4th May 1882, at the age of forty-six. He became a Member of the Institution in 1875.

SAMUEL DOWNING, LL.D., was the second son of the Rev. Samuel Downing, rector of Fenagh in the diocese of Leighlin, and was born on 19th July 1811, at Bagnalstown, County Carlow. He received his primary education at Kilkenny College, entered Trinity College, Dublin, in January 1829, and proceeded in due course to the degree of B.A. in the spring of 1834. There being then no school of engineering in Trinity College (it was instituted in 1842) he proceeded to Edinburgh, and availed himself during the session 1834-35 of the instruction given in that university in engineering subjects, obtaining at the same time a knowledge of mechanical drawing by spending all his leisure time in an architect's office. He subsequently became a pupil and then an assistant to the late Mr. Bushe, and was engaged for him on dock works in South Wales. He also designed and executed a road bridge, 560 ft. long, joining the island of Portland to the mainland, at an expenditure of only £4000, including road-approaches, toll-house, &c. He was for some time engaged as resident engineer on a section of the London and Birmingham Railway; and also filled a similar position on the Taff Vale Railway, where he had the superintendence of what were at that date considered some very special works, including an arched viaduct 106 ft. high on a 20-chain curve, constructed from a design of Brunel's with octagonal piers: of which he published a description in the Transactions of the Institution of Civil Engineers of Ireland (1850, vol. 4, part 1, p. 23). To that society he made several other communications, being one of its most active supporters, and for many years Vice-President. In 1846 he was appointed assistant

professor of engineering at Trinity College, Dublin, under the late Sir John MacNeill, who held the purely honorary post of professor; and from that time to within a few months of his death his whole energies were devoted to the instruction and advancement of his successive classes of students, and to the formation of the fine collection of engineering models and drawings which is now attached to the school. On Sir John MacNeill's resignation in 1852, he was appointed to the chair of the Practice of Civil Engineering; and in 1862 the university marked their appreciation of his services by conferring on him *honoris causâ*, in company with Sir Richard Griffith, Sir John MacNeill, and Mr. Robert Mallet, the then newly instituted degree of Master in Engineering. He had previously taken the Doctorate in Laws in 1856. His favourite study was that of hydraulics, on which subject, by aid of a grant from the Royal Irish Academy, he carried out many experiments; and in 1855 he published a treatise for the use of his pupils on the "Elements of Practical Hydraulics." This was so favourably received that he re-wrote and enlarged the second edition, which appeared in 1861; and also published in 1875 the first volume of a third enlarged edition, of which he had the second volume nearly ready for publication at the time of his death. He also published in 1875 the first volume of "Elements of Practical Construction," together with a volume of plates illustrating structures under direct tension and compression—a work which it is greatly to be regretted he was not spared to complete, having the manuscript of the remainder well in hand. He also printed for private circulation amongst his pupils a collection of specifications. A nervous temperament and retiring disposition militated greatly against his success as a speaker; but they were more than balanced by his great skill in teaching, and by his copious use of illustrations, drawn from his large stock of facts stored up from observation and from an extended course of reading. This knowledge he was ever ready to share with those old pupils and friends, scattered over all parts of the world, who used continually to consult him. He died on 21st April 1882, having thus completed his seventieth year, and having spent more than half his life in professorial duties. He was nominated an Honorary Life Member

of the Institution in 1865, after the visit of the Institution to Dublin in that year: the complete success of that visit was largely owing to the exertions of Dr. Downing, who acted as Honorary Local Secretary for the occasion.

ALFRED HARGREAVES GOWENLOCK was born in Manchester; but on Swindon being made a station and depôt of the Great Western Railway his parents removed thither, and he received a good practical education in the workshops and drawing office of the Great Western Railway Co., where he acquired considerable proficiency as a mechanic. After attaining the age of twenty-one he left Swindon to go to Deptford as the draughtsman of an engineering firm there. From thence he went to Messrs. Sharp Stewart and Co., Manchester; but after a few months he left to become chief engineer of the Assam Tea Co. After remaining there some time he decided to go to Calcutta, where he soon made himself known as a first-class practical engineer. About the year 1862 he became a partner in the firm of Jessop and Co., engineers and ironfounders, Calcutta, and remained in that business until his death, which occurred at Dulwich on 25th May 1882, at the age of forty-seven years. At that time he had been for some years the sole owner of the business, having survived all his partners. During his connection with the firm they executed many important works for government and private firms, and also for the rulers of independent native states. He became a Member of the Institution in 1871.

JAMES BAIRD HANDYSIDE was born in Glasgow on 4th October 1835, being the third son of the late Nicol Handyside, one of the original founders of the "Anchor" line of steam packets, by a daughter of the late John Baird of Shotts Iron Works. He served his time for six years with Messrs. Smith and Roger of Glasgow and Govan (now the London and Glasgow Engineering and Iron Ship Building Co.). After a voyage to Calcutta in a troop-ship as engineer, he went to Russia to represent the firm of W. R. and J. Handyside, contracting engineers. His stay in that country extended over eleven years, during the latter portion of which he was managing

director of the Ogeroff Iron Works of John Dye and Co., employing over 2000 hands. These works were subsequently acquired by the Russian Government, under whom he continued to act as manager. He also spent a short time in Siberia in the inspection of mines. On his return to Scotland in 1867, he was appointed Russian Consul in Glasgow, in succession to his father, who had held the office for upwards of forty years; and he continued to act in that capacity till 1873. Very shortly after leaving Russia he became connected with Mr. W. S. Thomson in the manufacture of railway springs and buffers; and this business, carried on afterwards under the firm of Thomson Sterne and Co., Limited, formed the nucleus of the various industries now prosecuted by them at the Crown Iron Works, Glasgow, including, in addition to the spiral-spring business, the manufacture of emery wheels, emery-grinding machinery, feed-water heaters and filters, and gas engines. Of this company Mr. Handyside was the managing director in Glasgow. In addition to the many excellent and useful emery machine-tools designed by him, may be mentioned his safety elastic disc-wheel for railway carriages and wagons. Both during his stay in Russia and after his return to this country, his singular faculty for organisation was well known and recognised, as were also the indefatigable exertions, often overtaxing his energies, put forth by him in the interests of the firm with which he was connected. He died at Glasgow, after a short illness, on 11th March 1882, at the age of forty-six. He became a Member of the Institution in 1879.

WILLIAM MACNAY was born on 25th December 1825 at Wallsend-on-Tyne: his father, Mr. Edward MacNay, being employed at the colliery bearing that name. His father removed thence in June 1835 to St. Helen's, Auckland, and filled the situation of overman at St. Helen's Colliery. About the latter end of the year 1838 William MacNay commenced work as clerk in the office at the Shildon Engine Works, then under the management of the late Mr. Timothy Hackworth. In 1839 he was removed to Soho Works, Shildon, and commenced as a moulder in the foundry. These works were then occupied by Mr. Thomas Hackworth, who was succeeded

by his brother Mr. Timothy Hackworth in May 1840. There Mr. MacNay remained until May 1841, when he left and returned to Shildon Engine Works, entering as an engineer's apprentice under the late Mr. William Bouch, Locomotive Superintendent of the Stockton and Darlington Railway. In 1856 he took charge of the Shildon Works under Mr. Bouch; and on the death of that gentleman in 1876 he continued in charge as manager under Mr. Edward Fletcher, until his death, which took place at Shildon on 1st June 1882. He became a Member of the Institution in 1865.

ROBERT CHARLES MAY, who died at Marseilles on 20th July 1882, from aneurism of the heart, was the son of Charles May, and was born in April 1829 at Ampthill in Bedfordshire: he was thus fifty-three years of age at his death. Charles May was a man of remarkable ingenuity, and was a partner in the firm of Ransomes and May, Ipswich, to whom Robert Charles May was apprenticed. After he had become an outdoor manager there, he left Ipswich for an appointment on the South Eastern Railway as resident engineer. In 1854, about three years after his father had left Ipswich and settled in London as a consulting engineer, he followed his example, and soon acquired a very considerable practice in gas, mill, and railway engineering. He was largely employed as superintending engineer in the construction of fixed and moving railway plant for home and foreign railways. He constructed in 1853 the outfall of the Wallands and Denge marshes at "Jury's Gut" in Kent, and placed there a reservoir or tidal pen, at the sea end of which were draw-gates, and at the land end self-acting tidal doors. The tidal water was thus penned in, and formed a sufficient scour to keep the outfall clear of the shingle and sand which travel west to east with the tide on that coast. In later years he devoted some attention to mining work, and was also largely employed as an expert witness and arbitrator in patent infringement cases &c. He became a Member of the Institution in 1863.

WILLIAM MENELAUS was of Scotch extraction, having been born in Edinburgh in 1818. He first entered the service of a Scotch

firm of engineers and millwrights; and subsequently came south and obtained an appointment in London. Whilst so employed he was sent to Wales to do some work in connection with a corn mill on the estate of Mr. Rowland Fothergill, at Hensol Castle, Cowbridge. His conduct at that time led to his being offered an engagement at the iron works of Messrs. Fothergill and Scales at Abernant. This offer he accepted, and subsequently became manager of the mills. In 1844 he was appointed engineer of the Aberdare Works, and in 1851 he became engineer to the Dowlais Works. In 1856, on the retirement of the late Mr. John Evans, he took the entire management of the latter works, a post which he retained until the time of his death. Mr. Menelaus' professional history during the past thirty years may be said to be the history of Dowlais. How the works grew under his management is known to all connected with the iron trade, and their growth has not been in size merely but in completeness and in powers of varied production. Mr. Menelaus was an early believer in steel; and the first attempt to carry out the Bessemer process on a commercial scale was made at Dowlais. This first attempt failed; but subsequently, when the details of the process had been further developed, it was again taken up there, and is carried out at Dowlais on an immense scale (see Proceedings 1880, pp. 321–3, and 1874 pp. 239–41). Mr. Menelaus also took an active part in the development of mechanical puddling, upon which he contributed a paper to the Institution at the Paris meeting in 1867 (p. 151). He was the founder of the South Wales Institute of Engineers; and he was from the first associated with the establishment of the Iron and Steel Institute in 1869, of which body he was the President in 1875–6; while in 1881 he was awarded the Bessemer medal (Journal 1881, p. 6). Mr. Menelaus was a particularly well-read man, not only, nor mainly, in subjects connected with engineering; but in history, political economy, and above all in the varied literature of Scotland: probably not many men knew more intimately the poetry of his native land. He was also an earnest lover of art; one of the last acts of his life was to present the town of Cardiff a collection of pictures of very considerable value. He became a Member of the Institution in

1857, was elected on the Council in 1868, and was for several years a Vice-President. In 1881 he was selected by the Council for the office of President, but he declined it on account of failing health. He died at Tenby on 30th March 1882, aged sixty-three.

THOMAS ORMISTON, C.I.E., was born in Edinburgh on 28th July 1826, and received his education at Glasgow. In 1846 he entered the service of the trustees of the River Clyde Navigation in the engineer's department, and shortly after became chief assistant, being for some time in entire charge of the works. In 1855 Mr. James Walker, then the consulting engineer to the River Clyde Trustees, appointed him principal assistant in the office of Messrs. Walker Burges and Cooper, in London. Here he continued until the beginning of 1862, and during this period he frequently accompanied the late Mr. Walker to the many important works upon which he was engaged to report, amongst others the harbours in the Isle of Man, the River Mersey, the extension of the Bute Docks at Cardiff, and many lighthouses. He was entrusted with the entire charge of the erection of the lighthouse on the Needles Rock during 1856–7. No contractor being employed, he designed the whole of the necessary plant, and carried out the works to the entire satisfaction of Mr. Walker and the Trinity Corporation, receiving a testimonial from the latter on the completion of the works.

Having been engaged in the preparation of the designs for the foundation of the Plymouth Breakwater Fort, the contract for which was let to Messrs. Henry Lee and Son, Mr. Ormiston accepted from Messrs. Lee the appointment as their engineer in sole charge of the works. These he continued to direct until near their completion in October 1864, when he received the appointment of chief engineer to the Elphinstone Land and Press Co. of Bombay, formed for the purpose of reclaiming a large extent of land from the foreshore of the harbour, the formation of a series of tidal basins for native craft and boats, the construction of warehouses, roads, &c. Although the works had been commenced in 1859, only about 81 acres had been reclaimed when Mr. Ormiston took charge in January

1865. He immediately reorganised the establishment, appointed a proper staff, and reduced the number of workmen by two-thirds; and operations proceeded rapidly. By the year 1870 the whole foreshore, 328 acres in extent, had been reclaimed and converted into a valuable estate, and nine miles of roads, from 40 feet to 80 feet wide, ten miles of drains, and two miles of permanent sea-walls, had been constructed, affording basins for the native craft, with 70 acres of wharf space and extensive shed and warehouse accommodation. The Government, being alive to the importance of these works, purchased the Elphinstone estate in April 1870, and took over the services of Mr. Ormiston as engineer, transferring to his charge the reclamation works in Mody Bay, which had for some time been in progress. In 1873 the Bombay Port Trust was formed, which took over the administration of the entire harbour of Bombay, Mr. Ormiston being appointed chief engineer.

After the constitution of the Port Trust, Mr. Ormiston, convinced of the necessity for improved appliances to meet the increasing trade, began persistently to advocate the construction of a wet dock with the most modern hydraulic appliances. In July 1875 orders were given to proceed with the works of this the first wet dock of any extent in India. The first stone of the Prince's Dock was laid by His Royal Highness the Prince of Wales on 11th November 1875; the last stone was set, and the water admitted, on 10th April 1879, and the dock was finally opened for traffic on 1st January 1880.

In addition to the reclamation and dock works, Mr. Ormiston erected the Prongs Lighthouse, a tower 150 feet high on a dangerous reef, at the entrance to Bombay harbour. He also designed the lighthouse in course of erection on the Sunk Rock near the harbour, and erected numerous beacons and landmarks.

Mr. Ormiston was for many years a justice of the peace for Bombay, and was entrusted with many arbitration cases for Government and individuals. He was consulted on harbour and other works in different parts of India, and designed the Albert Edward breakwater now in course of construction under native engineers, to form a harbour for the town of Mandvi, on the coast

of Kattywar; also a breakwater for Verawal on the same coast, &c. In 1879 he visited Cyprus at the request of the Foreign Office, and prepared a report and design for a harbour at Famagusta.

In 1877 he relinquished the post of chief Resident Engineer, and became Consulting Engineer to the Bombay Port Trust in London. His last visit to India was to attend the opening of the Prince's Dock in January 1880, on which occasion he received the decoration of Companion of the Indian Empire.

In February 1881 he visited Venezuela in South America, in his capacity as Chairman of the Bolivar Railway; he minutely inspected the whole of the line, and introduced such changes in the management as he considered desirable. Early in 1882 he was obliged to give up all work, and died at Freshwater, Isle of Wight, on 9th July 1882, at the age of barely fifty-six. He became a Member of the Institution in 1880.

George Albert Pitts was born at St. John's, Newfoundland, on 28th May 1849, and received his education there. In his eighteenth year he entered the department of Engineering and Applied Sciences at King's College, London, where in 1869 he was awarded a prize for manufacturing art. He also gained certificates for physics and practical work, and his associateship. In 1870 he apprenticed himself to Messrs. John Elder and Co., Glasgow, for three years, the usual term of five years being curtailed on account of his competency in practical work. In 1873 he entered the drawing office of Messrs. Laird at Birkenhead. Afterwards he went as an engineer in the steamship "Olbers" to the Brazils and elsewhere. In 1875 he went out to St. John's, Newfoundland, as superintendent of steamers and factories; and acted there as consulting engineer to the Government for local steamers, &c. In the autumn of 1881 he returned to England to establish himself as a consulting engineer; and whilst so engaged in Merionethshire, North Wales, he was attacked by confluent smallpox and suddenly died at Glanyrafon, near Ganllwyd, on 29th March 1882, in the thirty-third year of his age. He became a Member of the Institution in 1878.

WILLIAM POWELL, who died suddenly on 22nd May 1882 at his residence, Carleton, near Pontefract, was born in 1824 at the village of Hoyland near Barnsley, and was educated at a private school at that place. When little more than a boy he was employed at the rolling mills of the Milton Iron Works. His first step in advance from this position was to the drawing office of the same establishment. There he remained some time, and became one of the most expert draughtsmen of the place. Subsequently he removed to Rotherham, and was employed on the staff of the late Mr. Charles Bartholomew, engineer to the South Yorkshire Railway; where ample scope, of which he availed himself to the fullest extent, was afforded him for acquiring practical knowledge as a civil engineer. The experience gained in the great rock excavations on this line and in bridge building was of material service to him on his taking the position of engineering assistant to Mr. John Towlerton Leather, contractor, upon the great breakwater works at Portland. In the construction of this important national undertaking, in the excavations of the ditches of the Verne citadel, the construction of military roads, &c., Mr. Powell was engaged about twelve years; and so highly were his services appreciated by Mr., now Sir John Coode, the engineer in chief of the Portland breakwater, that he was offered the appointment of resident engineer on the harbour works then about to be commenced by the Government of the Isle of Man. From 1867 to 1879 Mr. Powell was employed in the construction of the breakwater at Port Erin, the new landing pier, breakwater, and quays at Douglas, and the harbour works at Ramsey, Peel, and other places in the island. The most important work carried out by him was the construction of the Loch promenade at Douglas, of which he was engineer in chief. He became a Member of the Institution in 1867.

CHARLES SMITH was a native of Arbroath in Forfarshire, having been born at Latham Grange on 5th September 1843. He was educated at Arbroath High School, and at the age of sixteen was apprenticed to Messrs. Randolph Elder and Co., engineers, Glasgow. About three years later he was permitted to suspend his

apprenticeship, and to go for a time to study civil engineering at Dollar College near Stirling. After remaining there for one session he returned to Glasgow in 1862 to complete his apprenticeship, and rapidly became one of the leading draughtsmen in Messrs. Randolph Elder and Co.'s office. When just on the point of completing his twenty-first year he was appointed chief draughtsman at the works of Messrs. James Howden and Co., marine engineers, Glasgow. Five months later he returned to his former employers (now Messrs. John Elder and Co.) as chief draughtsman, and remained about five years in that position, acquiring most valuable experience in designing all kinds of machinery for marine propulsion.

His career in Glasgow was coeval with the rise and development of the compound engine, of which he was a staunch advocate; and when in 1870 he succeeded Mr. G. W. Jaffrey as manager at Messrs. Thomas Richardson and Sons' works at Hartlepool, he introduced there the type of compound engine, with link-motion valve-gear and horizontal surface-condenser, which has become almost universally adopted. He was also a firm advocate of the double-ended cylindrical multitubular marine boiler, having repeatedly proved its superiority as an economical steam generator over the single-ended type; and so successful was his practice in this respect that by far the greater number of vessels fitted out by Messrs. Thomas Richardson and Sons are now specified by their owners to be furnished with them. Although retaining the same general type of engine, Mr. Smith introduced numerous improvements in detail, especially of late years, and kept the machinery produced at Hartlepool in the very front rank of marine engineering practice. In 1878 he became a partner in the firm of Messrs. Thomas Richardson and Sons. He was also a town councillor of Hartlepool, and held other public offices. He was for some years President of the Glasgow Association of Engineers, and was a member of Council of the Cleveland Institution of Engineers. He became a Member of the Institution in 1873.

Amongst works not connected with marine engineering may be mentioned a design for "twin boilers" (illustrated in "Engineering," 11 January 1878); also a paper read before the Cleveland Institution

of Engineers in November 1877, on "A facile mode of Compounding Engines." In 1873 he proposed a system of crossing navigable channels at the ground level, which he called the "bridge ferry." It consisted of a "high level" bridge carried on columns; along this was drawn a truck of large dimensions, from the corners of which was suspended by crossed wire-ropes or chains a platform or carriage to accommodate passengers, vehicles, &c. (see "Engineering," 25 July 1873).

In character Mr. Smith combined with a brilliant intellect a keen observation and extraordinary powers of physical and mental endurance. His great capacity for painstaking in matters of minute detail contributed largely to his success as an engineer. Having suffered from sleeplessness he went abroad in May 1882, and on 12th June was unfortunately drowned while bathing in the Lake of Lucerne, at the early age of barely thirty-nine.

CHARLES PATRICK STEWART was born in 1823 in Dublin, where his father, the Hon. Keith Stewart, was at that time occupied in the Irish administration. He completed his education at Trinity College, Cambridge. On leaving the University he became a pupil in the then well-known marine engineering firm of Seward and Capel, and after completing his term of apprenticeship he entered into closer connection with the firm. In 1852 he became a partner in the firm of Sharp Brothers and Co., Atlas Works, Manchester, and so continued until 1863, when the private partnership was converted into a limited company. This change enabled Mr. Stewart to diminish the amount of his personal attendance in Manchester, but did not prevent him from devoting his continuous and almost daily attention to the interests of the business with which he had become so closely allied. He took great interest in all the mechanical inventions and developments of his time, and allied himself very closely with those engineers who led the van of mechanical and engineering progress. He became a Member of the Institution in 1859, Member of Council in 1862, and Vice-President in 1875. Suffering as he did from chronic deafness, he was unable to take prominent part in the more public work connected

with the Institution, or to accept the post of President which would otherwise have been offered to him; but he was a frequent attendant at the meetings both of the Institution and of the Council, where his opinion always carried the greatest weight. His quick appreciation of the successful adaptation of scientific principles to mechanical applications was especially shown in his rapid conclusion as to the value of the apparatus afterwards known by the name of the Giffard injector, which was first brought under his notice almost accidentally during a short trip on a French Mediterranean steamboat: on his recommendation the development of this invention was taken up by his firm, and the result has been almost to revolutionise the methods of water-supply for steam-raising purposes. To all other matters of practical engineering he gave the most continuous and careful attention, the benefit of which was evidenced in the continued success of the business with which he had connected himself. His death took place on 7th July 1882, at his residence, Silwood Park, Sunninghill, in the fifty-ninth year of his age.

WILLIAM HENRY THWAITES was born at Bradford on 9th July 1850, and died at his residence in Bradford on 18th December 1882, at the age of thirty-two. On the completion of his education he entered the Vulcan Iron Works, Bradford, then carried on by his father, Mr. Robinson Thwaites, and Mr. E. H. Carbutt, M.P., under the style of Thwaites and Carbutt. Here he acquired his business experience, and on 1st August 1876 became a partner in the firm of Thwaites Brothers, which then took possession of the works; in this position he remained until the date of his decease. He became a Member of the Institution in 1875.

JOHN WAKEFIELD was born on 31st December 1812 at West Moor, near Newcastle-on-Tyne. In 1830 he became connected with the Liverpool and Manchester Railway, and some years afterwards went to the London and Birmingham Railway, being stationed at Watford in charge of the repairing of the ballast engines &c. In 1838 he was appointed locomotive superintendent of the London and Greenwich Railway; and in 1845 took a similar position on the

Birkenhead Lancashire and Cheshire Junction Railway, where he remained until 1848. He was then appointed to a position in the locomotive department of the Great Southern and Western Railway of Ireland. In 1865 he became locomotive superintendent of the Dublin Wicklow and Wexford Railway, which position he held until his death on 4th February 1882, in the seventieth year of his age. During his long connection with railways he was the inventor of many valuable improvements in the locomotive &c., one of these being the single-eccentric valve-motion, of which a description was given to the Institution in 1855 (Proceedings 1855, p. 146). He became a Member of the Institution in 1863.

ROBERT WATSON was born at Hetton Colliery, in the county of Durham, on 8th January 1811, and served his apprenticeship there under Mr. Stephen Robinson, at that time chief engineer of the Hetton Collieries. He left Hetton Colliery to undertake the duties of engineer at Thrislington Colliery, and afterwards at Barrington Colliery in Northumberland, where he remained eight years. He then received the appointment of engineer at the Black Boy Collieries near Bishop Auckland, owned and managed by the late Mr. Nicolas Wood. During the seventeen years he was there he carried out several important improvements in the general colliery plant and machinery. On these collieries passing into the hands of Messrs. Bolckow Vaughan and Co, Mr. Watson was appointed engineer at Ferryhill Colliery, in which he had a pecuniary interest. This colliery was ultimately abandoned by the company then in possession of it; and in 1875 Mr. Watson received a similar appointment at the Brereton and Hayes Collieries in Staffordshire. This he held up to the time of his death, which took place on 15th December 1882, at the age of nearly seventy-two. He became a Member of the Institution in 1866.

ROBERT WILSON, who died at Matlock on 28th July 1882, was born in 1803 at Dunbar, on the east coast of Scotland, where his father was drowned in the third attempt of the lifeboat to save the remainder of the crew of the frigate "Pallas," which was cast

ashore in December 1810. As a boy he was particularly fond of aquatic amusements of every kind, and as early as 1808 the thought occurred to him that if something in the nature of a sculling oar could be fitted to the stern of vessels it would be free from the objections to side paddles. Later he tried some unsuccessful experiments with a small model; but the matter dropped until 1821, when the difficulty with which one of the new steamers overcame the ground swell in the harbour of Dunbar led to further experiments with what he now termed "rough-sea or storm paddles." In 1827 he made the acquaintance of Mr. James Hunter, who introduced him to the Earl of Lauderdale. That nobleman promised to try to induce the Admiralty to take up the invention. It was shown at the Dunbar Mechanics' Institution, and in 1828 the Highland Society appointed a committee, who testified to the success of his plan when tried at Leith in a very heavy sea. The Society granted him £10, but only on condition of receiving his model, which he very reluctantly gave up. In 1832 Mr. Hunter brought the matter before the Scottish Society of Arts, and a committee reported on it. A silver medal was awarded to the inventor, and the Society, through Sir John Sinclair, called the attention of the Admiralty to the subject. The Woolwich officers to whom it was referred made a brief and unfavourable report, and the inventor's hopes were dashed to the ground. These early experiments however were not lost; in prosecuting them Mr. Wilson was developing his inventive faculties, and as recently as 1880 the War Department made a grant of £500 for the use of his double-action screw-propeller as applied to the fish torpedo.

In 1832 Mr. Wilson was in business as an engineer in Edinburgh, in the North Back of Canongate; but a few years later he migrated to Manchester, and in 1838 was the manager of the famous Bridgewater Foundry at Patricroft, the birthplace of the steam hammer. The first hammer was delivered in August 1843 to the Low Moor Iron Works, and continued in use there until 1853, when Mr. Wilson, who was then engineer of that establishment, added to it what is known as the "circular balanced valve." In 1856, on Mr. James Nasmyth's retiring from his active industrial career, Mr. Wilson was recalled from Low Moor, and became managing partner in the firm

of Messrs. Nasmyth Wilson and Co. He maintained and increased the world-wide fame of his firm, and mindful of his own early difficulties was always ready to smooth the path of those who showed talent and industry.

He did not take any active part in local affairs, but for some years was President of the Patricroft Mechanics' Institution. In 1873 he was elected a Fellow of the Royal Society of Edinburgh. He became a Member of the Institution in 1857, and in the same year contributed, through Mr. Charles Beyer, a paper on a balanced slide-valve for steam engines (Proceedings 1857, p. 194). In 1877 he also contributed a paper on hydraulic presses for packing cotton &c.—a class of machines largely made at the Patricroft works (Proc. 1877, p. 349).

Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1883.

The THIRTY-SIXTH ANNUAL GENERAL MEETING of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 25th January, 1883, at Half-past Seven o'clock p.m.; PERCY G. B. WESTMACOTT, Esq., President, in the chair.

The Minutes of the last Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following New Members, Associate, and Graduates were found to be duly elected:—

MEMBERS.

DAVID DECIMUS COATH, ...	Rangoon.
CHARLES FRIEND COOPER, ...	London.
GEORGE DAVIDSON, ...	Sydney.
JOHN GEORGE HARDY, ...	Vienna.
ROBERT HARVEY, ...	Truro.
ERASMUS DARWIN LEAVITT, JUN., . .	Cambridgefort, U.S.
JAMES MELROSE, ...	Gibraltar.
ALEXANDER HENRY REED, ...	London.
THEODORE REUNERT, ...	Kimberley.
EDWARD ROBINS, ...	Trinidad.
WILLIAM SCHÖNHEYDER, ...	London.
RICHARD CHARLES THOMPSON, . . .	Sunderland.
BEAUCHAMP TOWER, ...	London.
JAMES WADDELL, ...	Soerabaya.

ASSOCIATE.

JAMES MACILRAITH, ... Glasgow.

GRADUATES.

WILLIAM HENDERSON, ... London.
ERNEST DE MÉRINDOL MALAN, . . . London.
PHILIP MARRACK, ... Greenwich.
ARTHUR WALTER PIGOTT, ... Gateshead.
CHARLES LIDDELL SIMPSON, ... Newcastle-on-Tyne.
GERALD SWALE, ... London.

The PRESIDENT said he desired, before calling upon the Secretary to read the Annual Report of the Council, to make a few observations.

The Institution was now entering upon the thirty-seventh year of its work, and it must be gratifying to all who were interested in its progress and welfare to know that its affairs were in a flourishing and sound condition. He might anticipate the report, which would be read presently, by stating, that if success and progress were measured by numbers and finance, then the year that had passed away might be looked upon as one of the most, if not the most, successful on record.

He imagined that the substantial progress the Institution was making might be due, in a measure, to the greater breadth they were giving to their labours. He alluded especially to the "Experimental Researches" into vexed and shadowy regions of mechanical and scientific matters of importance to an engineer, in which they had been fortunate enough to enlist the hearty co-operation of several eminent professors. Experiments were the very life-blood of engineering. Without them progress would be slow and uncertain, and the profession would not occupy the high position it held. Everything therefore that the Institution could do to assist and encourage experiments, and to record the results of experiments for reference and guidance, must promote good work and give more prominence and importance to its proceedings. The money the Institution was spending in this direction was money laid out at good interest.

The members would be asked to pass a further supply for this object; and he did not doubt they would readily support the recommendation of the Council.

The list of deceases of members for the past year was unhappily a long one; and many well-known and familiar faces, and several influential names in the profession, had passed away. The list of resignations and erasures was also rather long; but in spite of these drawbacks the number on the roll had steadily advanced.

The summer meeting, always looked forward to by many members as means of much instruction and enjoyment—a happy combination in fact of business and pleasure—would not, he could answer for it, fall short of their expectations this year. For it was with great pleasure he had to announce that a very hearty invitation had been sent across from their professional brethren in Belgium to visit them this year: which invitation the Council had accepted with much gratification. Belgium would be a new and interesting field to the Institution. The talent, the skill, and the business powers of Belgian engineers, together with their well-known courtesy and hospitality, would ensure a successful and enjoyable meeting.

He might be permitted in conclusion to draw attention for a moment to a peculiar and to his mind a significant feature in the list of papers announced for the present meeting: no less than three of them were given to the Institution by professors of science. Now, as always, they would hail the presence of eminent scientific men to assist their deliberations.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF COUNCIL.

1883.

The Council have pleasure in laying the following Annual Report before the Meeting, on this occasion of the Thirty-sixth Anniversary of the Institution.

At the end of the year 1882 the total number of names of all classes on the roll of the Institution was 1370, as compared

with 1276 at the corresponding period of the previous year. The increase arises as follows:—there were added to the register within the year 141 names of all classes; there were lost from the register by deceases 19 names of all classes, and by resignation or removal 28 names of all classes. This effective increase of 94 is the largest ever recorded in the annals of the Institution, while the number of elections is also much larger than in any previous year.

The following Deceases of Members of the Institution have occurred during the past year:—

Thomas Adams, ...	Manchester.
Charles Edwards Amos, ...	London.
Thomas Aveling, ...	Rochester.
Capt. Carlos Braconnot, ...	Paris.
Robert Briggs, ...	Philadelphia.
David Campbell, ...	Glasgow.
Frederick Cooper, ...	Bombay.
Samuel Downing, LL.D., ...	Dublin.
Alfred Hargreaves Gowenlock, ...	London.
James Baird Handyside, ...	Glasgow.
William MacNay, ...	Darlington.
Robert Charles May, ...	London.
William Menelaus, ...	Dowlais.
Thomas Ormiston, C.I.E., ...	London.
George Albert Pitts, ...	Newfoundland.
William Powell, ...	Pontefract.
Charles Smith, ...	Hartlepool.
Charles Patrick Stewart, ...	Sunninghill.
William Henry Thwaites, ...	Bradford.
John Wakefield, ...	Dublin.
Robert Watson, ...	Brereton.
Robert Wilson, F.R.S.E., ...	Patricroft.

Of these Mr. Menelaus and Mr. Stewart had both been Members of Council for many years, and also Vice-Presidents of the Institution, and had always taken the warmest interest in its success. Dr. Downing was an Honorary Life Member of the Institution, having been so nominated after the meeting at Dublin in 1865, the success of which was in large measure due to his exertions.

The following gentlemen have resigned their Membership in the Institution during the past year:—

JOHN ARMSTRONG, ...	Sunderland.
PAUL BARKER, ...	Yardley.
JAMES BURROWS, ...	Chorley.
WILLIAM FIRTH, ...	Leeds.
GEORGE EMERSON FORSTER (Associate), ...	Washington, Durham.
ARCHIBALD ADLEY FRANCIS (Graduate), . . .	London.
MATTHEW GRAY, ...	London.
JOHN HIGSON, ...	Manchester.
WILLIAM HORNSBY, ...	Grantham.
WILLIAM INGLIS, ...	Bolton.
EDWARD RUSSELL MORRIS, ...	London.
JAMES NELSON, ...	Newcastle-on-Tyne.
DUNCAN ROBERTSON, ...	Glasgow.
WILLIAM THOMAS GRANT WHITELOCK (Graduate),	Bowling.

The following gentlemen have ceased to be Members of the Institution during the past year:—

ALBERTO DE ARTEAGA (Graduate), ...	Monte Video.
HANS WILLIAM CASPERSEN, ...	Newcastle-on-Tyne.
WILLIAM CURRY, ...	Dublin.
THOMAS MARK ELLIOTT, ...	Fence Houses.
HOLMES HIRD, ...	Leeds.
EDWARD HUTCHINSON, ...	Darlington.
THOMAS WILLIAM MATTHEWS, ...	Stockport.
HENRY FULLWOOD ROSE, ...	Moxley.
ALFRED WALKER, ...	York.

The Accounts for the year 1882, having been passed by the Finance Committee, and having been audited by Messrs. Robert A. McLean and Co., Public Accountants, are now submitted to the Members (*see Appendix I.*, pp. 42–45). It will be seen that the receipts for the year have been £4660 9*s.* 2*d.*, while the expenditure has been £3748 12*s.* 5*d.*, showing a balance of receipts over expenditure of £911 16*s.* 9*d.* A Balance Sheet is also appended, showing the financial position of the Institution at the end of the year to be thoroughly satisfactory. It will be seen that the total investments and other assets amounted to £14,528 7*s.* 5*d.*, and that the liabilities

were *nil*, the capital of the Institution at the end of the year being therefore £14,528 7*s.* 5*d.* The greater part of this, as will be seen, is invested in Four per cent. Railway Debenture Stocks, registered in the name of the Institution, including the sum of £399 11*s.* 4*d.* invested during the year.

The three Committees on Experimental Research have all been pursuing their investigations during the past year. With regard to the Hardening, Tempering, and Annealing of Steel, the important investigation commenced by Professor Abel, C.B., F.R.S., has not been brought to a conclusion; but, in spite of his many other duties, he has been able to prepare an interim report, which will be read at the present Meeting. It will be followed by an interesting communication by Professor Hughes, F.R.S., on the "Molecular Rigidity of Tempered Steel," which, it will be seen, goes to confirm Professor Abel's hypothesis. The thanks of the Institution are due to Professor Abel, Professor Hughes, Mr. Paget, and others for their valuable services to the Committee. With regard to Riveted Joints, Professor Kennedy has carried out an important series of experiments on double riveted joints, both lap and butt joints; but the report is withheld, pending the completion of similar experiments with hydraulic instead of hand riveting. The thanks of the Committee are again due to Professor Kennedy for his exertions; and also to the Landore Siemens-Steel Co., Messrs. Fielding and Platt, Mr. Alfred Slater, Mr. R. H. Tweddell, and others, for their valuable, voluntary, and untiring services to the Committee. With regard to the experiments on Friction, which from various unavoidable causes had been considerably delayed, the Committee were able to arrange during the past year for their being carried out by Mr. Beauchamp Tower, at the Edgware Road Works of the Metropolitan Railway, with a machine specially designed for the purpose, and constructed by Messrs. Easton and Anderson. Mr. Tower has drawn up a report on the first series of Experiments, which were very extensive, comprising trials of several kinds of oil, with varying speeds, and varying pressures on the journals; beginning with moderate speeds and pressures. The Council are now carrying out further experiments, with different speeds and pressures. They feel that the

thanks of the Institution are specially due to Mr. Joseph Tomlinson, Jun., for giving both personal supervision and many important facilities, without which this subject could not have been brought to a practical test; and also to Professor Kennedy, Messrs. Easton and Anderson, and others, for their valuable services to the Committee.

The Council recommend "That £300 be placed in the hands of the Council, to be used by them, if they think it desirable, for experimental research on the subjects already undertaken, or on such new subjects as may be determined upon, such as the deterioration of iron from various causes, the strength and durability of iron and steel when subjected to torsion, or other similar subjects."

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. Feeling the great desirability of enlarging and improving the Library, the Council again invite the Members to make donations of books, original pamphlets, or reports, and in particular of the records of any experiments or researches made by themselves or their friends.

(*For List of Donations see Appendix II.*, p. 46.)

The last No. of the Proceedings for 1882 contains particulars of two important sets of experiments conducted by Messrs. Easton and Anderson, and kindly communicated by them to the Council. The Council trust that this example will be followed by others, and that the printing of records of experiments, of a sufficiently important character, may become a regular feature of the Proceedings.

The Meetings held in 1882 were the Annual General Meeting and the Spring Meeting, both in London, and lasting two days each; the Summer Meeting of three days at Leeds; and the Autumn Meeting at Manchester. Thus eight days in all were devoted to the reading and discussion of Papers, the list of which, as published in the Proceedings, is as follows:—

On Meters for registering Small Flows of Water; by Mr. J. J. Tylor.
On the Bazin system of Dredging; by Mr. Alfred A. Langley.

On Hydraulic Lifts for Passengers and Goods; by Mr. Edward Bayzand Ellington.

Riveted Joints, Experiments on High Bearing Pressures, Series X.; by Professor Alex. B. W. Kennedy.

On improved Appliances for Working under Water, or in Irrespirable Gases; by Mr. W. A. Gorman.

On Power Hammers with a Movable Fulcrum; by Mr. Daniel Longworth.

On Wool-Combing by Modern Machinery; by Mr. F. M. T. Lange.

On Machinery for the Sowing of Seed; by Mr. James J. Smyth.

On the History of Engineering in Leeds; by Mr. A. H. Meysey-Thompson.

On the Working of Blast-Furnaces of Large Size, at High Temperatures of Blast, with special reference to the Position of the Tuyeres; by Mr. Charles Cochrane.

On Mining Machinery; by Mr. Henry Davey.

On a Single-Lever Testing Machine; by Mr. J. Hartley Wicksteed.

On Governing Engines by regulating the Expansion; by Mr. Wilson Hartnell.

On an Automatic Hydraulic system for Excavating the Channel Tunnel; by Mr. Thomas R. Crampton.

On the Fromentin Automatic Boiler Feeder; by Mr. John Hayes.

On the Automatic Screw-Brake; by Mr. W. Parker Smith.

On a Centrifugal Separator for Liquids of different specific gravities; by Mr. Waldemar Bergh.

The attendances at the Meetings have been as follows:—There were at the Annual General Meeting 88 Members and 80 Visitors; at the Spring Meeting 73 Members and 33 Visitors; at the Summer Meeting 292 Members and 128 Visitors; and at the Autumn Meeting 56 Members and 29 Visitors.

The Summer Meeting at Leeds was one of the largest and most successful which the Institution has ever held. By the arrangement and on the invitation of the Local Committee, the Members were entertained at luncheon on each of the three first days in the Town Hall, adjoining the place of meeting, and the afternoons were thus set completely free for excursions. Two of the afternoons were devoted to inspecting the numerous works in and around Leeds, the third to a visit to the Textile Exhibition, &c., at Bradford. The last day of the meeting was devoted to a most successful excursion to Hull, a town which had never been visited by the Institution, but in which

they received a most hearty welcome from the Mayor and the Reception Committee, and had the advantage of inspecting both the old and new Docks, and other interesting works.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council in rotation, go out of office this day. The result of the ballot for the election of the Council for the present year will be reported to the Meeting.

APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	*s.*	*d.*	£	*s.*	*d.*
To Printing and Engraving Proceedings of 1882	772	7	1			
Less Authors' Copies of Papers, repaid	66	19	6	705	7	7
" Printing Library Catalogue and Index of Papers				4	6	0
" Stationery, Binding, and General Printing				190	11	4
" Rent				550	0	0
" Salaries and Wages				1,365	19	3
" Coals, Firewood, and Gas				24	15	0
" Fittings and Repairs				131	6	1
" Postages				235	3	0
" Insurance				3	7	9
" Travelling Expenses				22	12	7
" Petty Expenses				57	18	1
" Meeting Expenses—						
Printing	84	10	0			
Reporting	63	8	10			
Diagrams, Screen, &c.	25	14	8			
Travelling and Incidental Expenses	59	2	8	232	16	2
" Research				154	7	10
" Books purchased				34	8	9
" Drawings of Watt Models				35	13	0
Total Expenditure in 1882				3,748	12	5
Balance, being excess of Receipts over Expenditure, carried down				911	16	9
				£4,660	9	2

	£	*s.*	*d.*
To amount invested in £356 Midland Railway 4% Debenture Stock	399	11	4
Cash Balance at this date	1,234	1	6
	£1,633	12	10

APPENDIX I.

FOR THE YEAR ENDING 31ST DECEMBER 1882. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
118 *New Members at £2*	236	0	0			
6 *New Associates at £2*	12	0	0			
16 *New Graduates at £1*	16	0	0			
6 *Graduates transferred to Members at £1*	6	0	0	270	0	0
„ Subscriptions for 1882—						
1128 *Members at £3*	3,384	0	0			
28 *Associates at £3*	84	0	0			
78 *Graduates at £2*	156	0	0			
6 *Graduates transferred to Members at £1*	6	0	0	3,630	0	0
„ Subscriptions in arrear—						
56 *Members at £3*	168	0	0			
1 *Associate at £3*	3	0	0			
5 *Graduates at £2*	10	0	0			
2 *Members, instalments*	3	6	2	184	6	2
„ Subscriptions in advance—						
18 *Members at £3*	54	0	0			
2 *Graduates at £2*	4	0	0	58	0	0
„ Donation to Library				30	0	0
„ Interest—						
From Investments	370	14	11			
From Bank	47	19	7	418	14	6
„ Reports of Proceedings—						
Extra Copies sold				69	8	6
				£4,660	9	2

	£	s.	d.
By Balance brought down	911	16	9
Cash Balance 31st December 1881	721	16	1
	£1,633	12	10

Dr. **BALANCE SHEET,**

	£	s.	d.
Capital of the Institution at this date	14,528	7	5
	£14,528	7	5

(*Signed*) EDWARD A. COWPER
GEORGE B. RENNIE } *Finance Committee.*

AS AT 31ST DECEMBER 1882. *Cr.*

		£	s.	d.	£	s.	d.
By Cash—*In Bank, Deposit account*		700	0	0			
" " *Current* "		234	1	6			
In Secretary's hands		300	0	0	1,234	1	6
" Investments—							
£3,178 *London & N. W. Ry.* 4% *Debenture Stock*							
£2,200 *North Eastern* " " " "							
£2,466 *Midland* " " " "							
£1,800 *Great Western* " " " "							
£9,644	*cost*				9,617	7	6
Note—The Market Value of these investments at 31st Dec. 1882 was about £11,000							
" Subscriptions in Arrear					265	0	0
" Office Furniture and Fittings					350	0	0
" Library and Proceedings					2,661	18	5
" Drawings, Engravings, Models, Specimens, and Sculpture					400	0	0
					£14,528	7	5

Audited and Certified by

ROBERT A. McLEAN & Co., Chartered Accountants,
1 Queen Victoria Street, London, E.C.

APPENDIX II.

LIST OF DONATIONS TO LIBRARY.

Abridged Specifications of Air and Gas Engines; from Mr. Benjamin L. F. Potts.

Hydraulics and Hydraulic Motors, by Dr. P. J. Weisbach; from Mr. Michael M. Brophy.

Gas Firing, with a description of the Wilson system, by F. J. Rowan; from the author.

Essai sur les Inventions en Mécanique et sur leur Exploitation commerciale, by L. Poillon; from Mr. Henry Chapman.

Officieller Bericht über die auf der Ringbahn zu Arnheim in den Monaten April und Mai 1881 stattgefundenen Proben von Tramway-Locomotiven, by Fr. Th. Avé-Lallemant; from Mr. Charles Brown.

Preliminary Report of H. M. Commissioners on Accidents in Mines; from the Commission.

Photograph of Brown's Steam Tramway Locomotive; from Mr. Benjamin C. Browne.

Moyens de prévenir les Explosions dans les Mines, by Léon Somzée; from Mr. J. Walter Pearse.

Pile Voltaique, système L. Somzée; from Mr. J. Walter Pearse.

Des Mines à Grisou et des Dépressions atmosphériques, by Emile Harzé; from Mr. J. Walter Pearse.

Preservation of Foods by Cold, by T. B. Lightfoot; from the author.

The Management and Running of Marine Boilers in connection with Surface Condensers, and suggestions for preventing Scale and Oxidation, by John R. Fothergill; from the author.

Useful Information on Electric Lighting (3rd edition), by Killingworth Hedges; from the author.

The Treatment of Steel, by Messrs. Miller Metcalf and Parkin; from the authors.

Études sur la Combustion de la Houille et sur le Rendement des Chaudières à vapeur; from Mr. G. Blake Oughterson.

Trial of Engines and Boilers at Audley Hall Weaving Shed, Blackburn, by Michael Longridge; from the author.

Methods of Wind Measurement, by H. S. Hele Shaw; from the author.

Two Photographs of Compound Locomotive built at Crewe Works; from Mr. Francis W. Webb.

Progress and Development of the Marine Engine, by Francis C. Marshall; from the author.

Photograph of Tylor's Triplicate Water Meters; from Mr. J. J. Tylor.

The Marine Steam Engine, by Richard Sennett; from the author.

Influence of Temperature on the Strength and Ductility of Steel and Iron; from the Admiralty.

Tableau synoptique relatif aux Brevets d'invention, by Emile Barrault; from Mr. Henry Chapman.

Rivers and Canals, by L. F. Vernon-Harcourt; from the author.

Machines et Appareils ayant rapport à l'Industrie Textile à l'Exposition universelle de 1878 à Paris, by Paul Sée; from the Industrial Society of the North of France.

Wanderings between New York and San Francisco in the autumn of 1881, by R. P. Spice; from the author.

Chemin de fer métropolitain de la ville de Vienne, by M. Schaller; from Mr. Joseph Fogerty.

Catalogue of French Books; from Dulau and Co.

Admiralty Report upon the Effects of Heat on the Bending qualities of Iron, by J. F. Barnaby; from the Admiralty.

Simple and Self-acting Continuous Brakes, by F. T. Haggard; from the author.

Third-Class Passenger Traffic and the difficulties of conducting it, by F. T. Haggard; from the author.

Ventilation of the London Custom House and the Council Chamber of the Royal Institute of British Architects, by Robert Boyle and Son; from the authors.

Report on Motors (Air and Gas Engines) tested at the Exhibition held in Glasgow in Sept. and Oct. 1880, by St. John V. Day; from the author.

L'Horloge automatique dite Régulateur perpétuel Dardenne; from Mr. J. Walter Pearse.

Principles of Colliery Ventilation, by Alan C. Bagot; from the author.

Speed and Carrying of Screw Steamers, by William Denny, F.R.S.E.; from the author.

Foundations of Mechanics, by Walter R. Browne; from the author.

Cleveland Water Works, Ohio, Report for 1881; from Mr. M. W. Kingsley.

Spon's Encyclopædia of the Industrial Arts, Manufactures, and Raw Commercial Products, by Charles G. Warnford Lock; from Mr. W. C. Knight Clowes.

The Automatic Screw-Brake, by W. Parker Smith; from the author.

Practical Directory for the Improvement of Landed Property, by R. Scott Burn; from the author.

Spontaneous Combustion and Explosions occurring in Coal Cargoes, by Thomas Rowan; from the author.

Dockising River Avon, Reports on Floods, &c., by Thomas Howard, Robert Rawlinson, Henry John Marten, and G. J. Symons; from Mr. Henry J. Marten.

Triple Expansive Engines of SS. "Aberdeen," by A. C. Kirk; from Mr. William Parker.

Economy of Compound Engines, by William Parker; from the author.

Abhängigkeit der gleitenden Reibung von der Geschwindigkeit, by J. N. Franke; from the author.

Rückblick auf die Entstehung und den Bau der Gotthardbahn, by Dr. Wanner; from Herr J. Stocker.

Gotthardbahn Fahrordnung; from Herr J. Stocker.

Chart of form and arrangement of the Cloud Bands and Earth Currents, by G. Jinman; from the author.

List of Chinese Lighthouses, Light-Vessels, Buoys, and Beacons; from Sir Robert Hart, Inspector-General of Chinese Maritime Customs at Peking.

Boiler Explosions, by Edward B. Marten; from the author.

La Lumière Électrique, by Em. Alglave and J. Boulard; from Mr. Henry Chapman.

Report for 1881 of the Chief of the U.S. Bureau of Steam Engineering; from the author.

Report of the Board to recommend a Standard Gauge for Bolts, Nuts, and Screw-Threads, for the U.S. Navy; from the Chief of the Bureau of Steam Engineering.

Report of a Board of U.S. Naval Engineers on the Machinery of the Steamer "Anthracite"; from the Chief of the Bureau of Steam Engineering.

Report of a Board of U.S. Naval Engineers on the Mallory Steering and Propelling Screw as applied to the U.S. Torpedo Boat "Alarm"; from the Chief of the Bureau of Steam Engineering.

Report of a Board of U.S. Naval Engineers on experiments made for Testing Screw Propellers; from the Chief of the Bureau of Steam Engineering.

Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers, by Guilford L. Molesworth; from the author.

Six Photographs of Machinery, by Norman Selfe; from Mr. James W. Dunlop.

Esboço de um Manual Para os Fazendeiros de Assucar no Brazil, by Antonio Gomes de Mattos; from the author.

Hydraulic Machinery for Deep Mining, by Joseph Moore; from Mr. Ralph Moore.

Report on Madras Harbour, by Guilford L. Molesworth; from the author.

Locomotives with Wheels having Two Tyres, by A. Cottrau; from the author.

Designing Valve Gearing (Appendix), by E. J. Cowling Welch; from the author.

Report on the Inundation of Port Louis, February 1865; from Mr. J. R. Mosse.

Report on Colombo Harbour Works, Breakwater Construction and progress of preliminary works; from Mr. J. R. Mosse.

Papers relating to Flood Outlets for Colombo; from Mr. J. R. Mosse.

Administration Reports of the Public Works Department, Ceylon, 1876–80 inclusive; from Mr. J. R. Mosse.

Worcestershire Exhibition Catalogue, 1882; from Mr. W. Temple Bourne.

Catalogue of Machinery; from Messrs. Western and Co.

Accounts of Grazi and Tsaritsin Railway, 1880 and 1881 (Russian); from Mr. Thomas Urquhart.

Atlas of Water Pumping Engines, Pumps, Tanks, &c., of the Grazi and Tsaritsin Railway (Russian); from Mr. Thomas Urquhart.

Kreiselpumpen, by Gisbert Kapp; from the author.

Applied Mechanics, by Henry Taylor Bovey; from the author.

Catalogue of the North-East Coast Exhibition of Marine Engineering, &c.; from Mr. George B. Rennie.

Catalogue of National Exhibition of Models of Railway Appliances at Darlington; from the Secretary.

Constant Supply and Waste of Water, by George F. Deacon; from the author.

Report upon the Coalfields of Natal, by Frederic W. North; from the author.

Plan and Estimates of Navigation from Lough Neagh to Belfast, by Robert Whitworth; from Mr. Charles Manby, F.R.S.

Dimensions of Cast-Iron at various Temperatures, by W. J. Millar; from the author.

Plan of Hull Docks, 1881; from Mr. R. A. Marillier, Docks Engineer.

Étude sur le Rivetage, by G. Clauzel; from the author.

Papers on Mechanical Subjects, Parts I. and II., True Planes, Screw Threads, Standard Measures, and Rifled Small Arms, by Sir Joseph Whitworth, Bart.; from the author.

Photographs of Rail Bridges and Locomotives made at Esslingen; from Herr Emil Kessler.

The "Doterel" Explosion, by Mr. Thomas Rowan; from the author.

Reports on the Mineral Deposits of New Zealand; from the Government of New Zealand.

Manchester Ship Canal (4 Pamphlets); from the Secretary of the Canal.

Conservancy of Rivers &c., by J. H. Blake; from the author.

Utilisation des Forces Motrices du Rhône; from M. Arthur Achard.

Photograph of Express Locomotive with Joy's Gear on the Philadelphia and Reading Railroad; from Mr. David Joy.

Photographs of early Locomotives; from Mr. Ramsey Kendal.

Useful Rules and Tables, by W. J. Macquorn Rankine (new edition); from Messrs. Charles Griffin and Co.

Report on the use of Cast Steel for Crank Shafts, by William Parker; from the author.

Résultats des expériences faites à l'Exposition d'Électricité, by Messrs. Allard, Joubert, F. Le Blanc, Potier, et Tresca; from M. Henri Tresca.

Reports of the Academy of Sciences, France; from the Academy.
Reports of the Royal Academy of Sciences, Belgium; from the Academy.
Reports of the Royal Institute of Engineers, Holland; from the Institute.
École des Ponts et Chaussées, Paris, Engravings and Library Catalogue; from the School.
Annales des Ponts et Chaussées, Paris; from the Directors.
Proceedings of the French Institution of Civil Engineers; from the Institution.
Journal of the French Society for the Encouragement of National Industry; from the Society.
Report of the French Association for the Advancement of Science; from the Association.
Journal of the Marseilles Scientific and Industrial Society; from the Society.
Proceedings of the Engineers' and Architects' Society of Milan; from the Society.
Proceedings of the Engineers' and Architects' Society of Rome; from the Society.
Proceedings of the Engineers' and Architects' Society of Florence; from the Society.
Proceedings of the Engineers' and Architects' Society of Canton Vaud; from the Society.
Proceedings of the Engineers' and Architects' Society of Austria; from the Society.
Proceedings of the Architects' and Engineers' Society of Hanover; from the Society.
Proceedings of the Engineers' and Architects' Society of Prague; from the Society.
Proceedings of the Industrial Society of St. Quentin; from the Society.
Proceedings of the Industrial Society of Mulhouse; from the Society.
Proceedings of the Industrial Society of the North of France; from the Society.
Proceedings of the Saxon Society of Engineers and Architects; from the Society.
Proceedings of the Swedish Society of Engineers; from the Society.
Journal of the Norwegian Polytechnic Society; from the Society.
Journal of the Belgian State Railways; from the Railway Committee.
Journal of the Franklin Institute; from the Institute.
Transactions of the American Society of Civil Engineers; from the Society.
Transactions of the American Institute of Mining Engineers; from the Institute.
Report of the Smithsonian Institution; from the Institution.
Proceedings of the United States Naval Institute; from the Institute.
Proceedings of the American Meteorological Society; from the Society.
United States Patent Office Gazette; from the Office.
Professional Papers on Indian Engineering; from the Thomason College.
Proceedings and Journal of the Asiatic Society of Bengal; from the Society.
Report of the Sassoon Mechanics' Institute, Bombay; from the Institute.
Proceedings of the Institution of Civil Engineers; from the Institution.
Journal of the Iron and Steel Institute; from the Institute.

Transactions of the Society of Engineers; from the Society.
Journal of the Society of Telegraph Engineers; from the Society.
Transactions of the Institution of Civil Engineers of Ireland; from the Institution.
Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Transactions of the Institution of Engineers and Shipbuilders in Scotland; from the Institution.
Proceedings of the Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers; from the Institute.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers; from the Institute.
Proceedings of the Cleveland Institution of Engineers; from the Institution.
Transactions of the West of Scotland Mining Institute; from the Institute.
Proceedings of the Royal Society of London; from the Society.
Proceedings of the Royal Society of Edinburgh; from the Society.
Proceedings of the Royal Institution; from the Institution.
Transactions of the Institution of Surveyors; from the Institution.
Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors; from the Association.
Journal of the Royal United Service Institution; from the Institution.
Papers of the Royal Engineer Institute; from the Institute.
Proceedings of the Royal Artillery Institution; from the Institution.
Journal of the Royal Agricultural Society of England; from the Society.
Journal of the Statistical Society; from the Society.
Report of the British Association for the Advancement of Science; from the Association.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Report of the Miners' Association of Cornwall and Devon; from the Association.
Transactions of the Institution of Naval Architects; from the Institution.
Transactions of the Royal Institute of British Architects; from the Institute.
Report of the British Association of Gas Managers; from the Association.
Proceedings of the Physical Society of London; from the Society.
Proceedings of the Literary and Philosophical Society of Manchester; from the Society.
Report of the Manchester Geological Society; from the Society.
Journal of the Royal Scottish Society of Arts; from the Society.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Transactions and Proceedings of the Royal Irish Academy; from the Academy.
Transactions of the Liverpool Engineering Society; from the Society.
Journal of the Liverpool Polytechnic Society; from the Society.

Proceedings of the Birmingham Philosophical Society; from the Society.

Journal of the Society of Arts; from the Society.

Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.

Report of the Boiler Insurance and Steam Power Company; from Mr. Niel McDougall.

Report of the National Boiler Insurance Company; from Mr. Henry Hiller.

Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.

Catalogue of the Liverpool Free Public Library; from the Committee.

The Engineer; from the Editor.
Engineering; from the Editor.
Iron; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Colliery Guardian; from the Editor.
The Iron and Coal Trades Review; from the Editor.
Ryland's Iron Trade Circular; from the Editor.
Revue générale des Chemins de fer; from the Directors.
Der Civilingenieur; from the Editor.
The Railroad Gazette; from the Editor.
The Railway Engineer; from the Editor.
The Engineering and Mining Journal; from the Editor.
The Telegraphic Journal and Electrical Review; from the Editor.
The Fireman; from the Editor.
The Marine Engineer; from the Editor.
The Contract Journal; from the Editor.

The President moved the adoption of the Annual Report of the Council, which was carried unanimously.

The President announced that the Ballot Lists for the election of Officers had been opened by a committee of the Council, and the following Members of Council were found to be elected for the present year:—

PRESIDENT.

PERCY G. B. WESTMACOTT, ...	Newcastle-on-Tyne.

VICE-PRESIDENTS.

THOMAS R. CRAMPTON, ...	London.
JEREMIAH HEAD, ...	Middlesbrough.

MEMBERS OF COUNCIL.

DANIEL ADAMSON,.	Manchester.
J. HAWTHORN KITSON, ...	Leeds.
BERNHARD SAMUELSON, M.P., F.R.S., .	London.
JOSEPH TOMLINSON, JUN., ...	London.
RALPH H. TWEDDELL, ...	London.
R. PRICE WILLIAMS, ...	London.

The Council for the present year would therefore be as follows:—

PRESIDENT.

PERCY G. B. WESTMACOTT, ...	Newcastle-on-Tyne.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., ...	Newcastle-on-Tyne.
SIR FREDERICK J. BRAMWELL, F.R.S., .	London.
EDWARD A. COWPER, ...	London.
THOMAS HAWKSLEY, F.R.S., ...	London.
JAMES KENNEDY, ...	Liverpool.
JOHN RAMSBOTTOM, ...	Alderley Edge.
JOHN ROBINSON, ...	Manchester.
C. WILLIAM SIEMENS, D.C.L., LL.D., F.R.S., ...	London.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., ...	Manchester.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, F.R.S., ...	Northallerton.
CHARLES COCHRANE, ...	Stourbridge.
THOMAS R. CRAMPTON, ...	London.
JEREMIAH HEAD, ...	Middlesbrough.
GEORGE B. RENNIE, ...	London.
FRANCIS W. WEBB, ...	Crewe.

MEMBERS OF COUNCIL.

DANIEL ADAMSON, ...	Manchester.
WILLIAM ANDERSON, ...	London.
DAVID GREIG, ...	Leeds.
J. HAWTHORN KITSON, ...	Leeds.
FRANCIS C. MARSHALL, ...	Newcastle-on-Tyne.
ARTHUR PAGET, ...	Loughborough.
RICHARD PEACOCK, ...	Manchester.
JOHN PENN, ...	London.
SIR JAMES RAMSDEN, ...	Barrow-in-Furness.
E. WINDSOR RICHARDS, ...	Middlesbrough.
WILLIAM RICHARDSON, ...	Oldham.
BERNHARD SAMUELSON, M.P., F.R.S., .	London.
JOSEPH TOMLINSON, JUN., ...	London.
RALPH H. TWEDDELL, ...	London.
R. PRICE WILLIAMS, ...	London.

The PRESIDENT said he might take that opportunity of stating that the Council had that day nominated Prof. F. A. Abel, C.B., F.R.S., and Prof. Alex. B. W. Kennedy, as Honorary Life Members of the Institution, in recognition of their great services in connection with the experiments on Steel and on Riveting respectively. The honour thus conferred would, he was sure, be felt to reflect honour on the Institution itself.

The following papers were then read and discussed:—

Report on further Experiments bearing upon the question of the condition in which Carbon exists in Steel; by Professor F. A. Abel, C.B., F.R.S., of Woolwich.

On the Molecular Rigidity of Tempered Steel; by Professor D. E. Hughes, F.R.S., of London.

On the motion of the President, votes of thanks were passed to the authors for their papers.

At 9.45 p.m. the Meeting was adjourned till the following evening.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 26th January, 1883, at Half-past Seven o'clock p.m.: GEORGE B. RENNIE, Esq., Vice-President, in the chair, in the absence of the President through indisposition.

The following papers were read and discussed:—

On the Working of Blast Furnaces, with special reference to the Analysis of the Escaping Gases; by Mr. Charles Cochrane, of Stourbridge, Vice-President.
On the St. Gothard Tunnel; by Herr E. Wendelstein, of Lucerne.

On the motion of the Chairman, votes of thanks were passed to the authors for their papers. It being then Ten o'clock, a paper on the Strength of Shafting when exposed both to Torsion and End Thrust, by Professor A. G. Greenhill, of Woolwich, was postponed to the next meeting.

The CHAIRMAN moved a vote of thanks to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of the Institution. The vote was carried by acclamation.

The Meeting then terminated.

REPORT ON FURTHER EXPERIMENTS BEARING UPON THE QUESTION OF THE CONDITION IN WHICH CARBON EXISTS IN STEEL.

BY PROF. F. A. ABEL, C.B., F.R.S., Hon. M. Inst. C.E.

In the Report presented to the Committee on Steel in October 1881, an account was given of the results of some preliminary experiments, which were carried out with the object of ascertaining, in the first instance, whether any characteristic differences could be established, in structure or chemical condition, between thin discs of steel cut from one and the same piece of that metal, but differing from each other in regard to the treatment to which they had afterwards been subjected. It will be remembered that it was not possible to throw any light upon the mechanical condition, or structure, of the different specimens, by submitting them to the operation of the solvent (a chromic acid solution) specially selected on account of its gradual action; it being impracticable to check the action at any period when the portions of the discs least acted upon, or not at all attacked, could be retained upon the support on which they were placed, in the positions which they originally occupied in the very thin sheet-metal.

Considerable differences were found to exist between the total amounts of carbon contained in different discs, from one and the same piece of steel, but in the hardened, tempered, and annealed states respectively. The proportion in the specimens of annealed steel was comparatively very low: and this difference being confirmed by the examination of another series of discs, an enquiry into the course pursued in annealing the steel discs led to further experiments, which appeared clearly to establish the fact that the reduction in the proportion of carbon in the steel during annealing was due to the prolonged exposure of the discs to heat in contact with, or close proximity to, the wrought-iron plates between which they were confined.

A thorough confirmation of the correctness of this conclusion being considered desirable by the Committee, Mr. Paget was so good as to include, when preparing another series of steel discs from one and the same lot of steel, a number of specimens which were submitted to the annealing process in various ways.

In one series, the discs were enclosed in sets of seven, one set between wrought-iron plates, planed and cleaned, and the other between cast-iron plates, planed and cleaned; this combination being again enclosed in wrought-iron and in cast-iron boxes respectively, and packed round with burnt soot. A set of three discs was similarly annealed between black wrought-iron plates, and another set of three between two blocks of fire-clay, enclosed in a cast-iron box and packed round with calcined magnesia. The examination of these sets of discs thus annealed was expected to demonstrate the nature and the extent of the effects of prolonged heating between wrought-iron and cast-iron plates, as to the abstraction of carbon from, or addition of carbon to, thin steel discs in contact with the plates, or separated from them by intervening discs; and also to show what effects, in regard to the condition of carbon in the steel, may be due purely to the process of annealing.

As yet it has been impossible to proceed far with the examination of these plates; but the extreme decarbonising effect of prolonged heating of steel in contact with wrought iron was demonstrated by the following experiment. Some steel discs of the usual dimensions (2·5 in. in diameter and 0·01 in. thick), and containing about 1 per cent. of carbon, were annealed singly between two wrought-iron plates in the manner already described. That is, the arrangement containing the packed plates was raised in an annealing furnace to a bright red heat, sufficient to scale the cast-iron box, but not sufficient to fuse it; the fire was then slackened off, banked up, and the box left in the furnace undisturbed for twenty-four hours. Upon afterwards heating the plates thus treated to redness, and plunging them into cold water, they remained as soft as malleable iron; and the examination of one of the discs by Mr. W. H. Deering (who has carried out the whole of the experimental work connected with this Report) showed that the carbon had been reduced to 0·1 per cent.

Before proceeding with the comparative examination of the various series of discs, annealed, hardened, and tempered blue and straw, with which the author has been furnished by Mr. Paget, it was considered important to acquire further information regarding the composition and character of the carbon-iron compound which had been obtained, in the experiments described in the last Report, by treatment of the thin sheet steel with chromic acid solution (produced by mixing a solution of potassium bichromate, saturated in the cold, with one-twentieth of its volume of pure concentrated sulphuric acid).

It was stated in the former Report (Proceedings 1881, pp. 703–4) that the cold-rolled and the annealed discs thus treated had yielded in different proportions a black scaly or spangly substance, which was attracted by the magnet, and which was found to contain, in combination with iron, an amount of carbon equal practically to the whole amount which had been found to exist in corresponding discs, in the same cold-rolled and annealed condition, taken from the same piece of metal. On the other hand, a disc of hardened steel, which was submitted to the same treatment, yielded only a small quantity of dark particles of similar appearance, in admixture with some lighter-coloured sediment; and the carbon in the residue, obtained in this instance, amounted only to about one-sixth of the total carbon in the steel. An examination of the proportion which the carbon bore to the iron in this particular residue showed it to be decidedly higher than in the spangly residues furnished by the cold-rolled and the annealed samples. The several residues of the latter class resembled each other very closely in composition, and the ratios of the carbon to the iron in each case corresponded closely to the ratio in an iron carbide having the formula $Fe_6 C_5$.

In a second experiment (Proceedings 1881, p. 704, foot-note) made with one of the cold-rolled discs, the metal was exposed to the prolonged action of a solution consisting of the same kind of chromic acid liquor as used in the previous experiments, but mixed with an additional quantity of concentrated sulphuric acid (40 grammes to 500 cubic centimetres of the solution). The heavy grey-black powder which had separated from this disc (the solution being completed

in twenty-four hours) was allowed to remain in the solvent for nine days. Its analysis showed it to contain a comparatively small proportion of iron; which appeared to indicate that the carbon-iron compound, which is at first separated, does not resist the further action of the chromic liquor, in the presence of a considerable excess of sulphuric acid.

The quantities of steel operated upon in those experiments were unavoidably small; and it appeared interesting, and possibly important, to ascertain whether the indications furnished by the results referred to,—that the condition of combination of carbon with iron, in steel, differs in samples of one and the same metal if they have been submitted to decidedly different treatment,—were confirmed by more extended experiments; also to learn more regarding the nature of the magnetic carbon-iron product eliminated by the action of a slowly oxidising solvent upon annealed (or cold-rolled) steel; *e.g.* (1) whether its composition is independent of the strength, within rather wide limits, of the chromic solution employed for its elimination; (2) whether, within those limits, a constant quantity of the carbide is obtained from 100 parts of one and the same description of steel; and (3) what proportions of the carbon in this carbide would remain unconverted into hydrocarbon upon treatment of the latter with hot chlorhydric acid.* With these objects in view the author obtained from Mr. Paget a thin sheet of steel in the same condition as delivered to him from the Birmingham makers, having been cold-rolled and cross cold-rolled, and annealed several times between the various rollings. The weight of this plate was 175 grammes (2700·6 grains) and its thickness about 0·2 mm. (0·008 in.).

Mr. Deering's analysis of a sample of this steel plate, taken from the same part whence specimens were afterwards cut, showed it to contain—Carbon 1·144 per cent.; silicon 0·166 per cent.; manganese 0·104 per cent.

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* If carbon or carbo-hydrate were left after this treatment, it would indicate that some proportion of the carbon in the steel had been separated as such, or as carbo-hydrate, by the chromic treatment; or, that some proportion of the carbide first separated had been gradually attacked by the chromic liquor, and in such a manner that, during the oxidation of the iron in the carbide, the carbon had been partly or completely eliminated, as carbo-hydrate.

The individual pieces of the steel plate submitted to the action of the solvent weighed from 7 to about 7·5 grammes (108 to 115·7 grains). Before treatment, the pieces were rubbed bright with emery-flour, then washed with ether, and dried in a clean cloth.

The preparation of the chromic acid solutions employed in these experiments is best illustrated by a description of the production of the solvent used in obtaining what will presently be designated Preparation 2.

This liquor was prepared by adding to a filtered solution of potassium bichromate, saturated in the cold (67° to 68° F.) and containing 99 grammes of the salt per 1000 cubic centimetres of solution, a proportion of concentrated sulphuric acid (having the full specific gravity) corresponding to 0·9 gramme of acid per 1 gramme of the potassium salt. The following chemical equation represents the action of a solution of this description upon iron:—

$$Fe_2 + K_2\,Cr_2O_7 + 8\,H_2\,SO_4 = Fe_2\,(SO_4)_3 + Cr_2\,(SO_4)_3 + 2\,KHSO_4 + 7\,H_2O.$$

According to this equation the theoretical requirement of acid is 0·84867 gramme to 1 gramme of the bichromate, and 1000 c. c. of the solution thus prepared would suffice to dissolve 9·226 grammes of iron. Each piece of steel immersed in that quantity of liquid weighed, as stated, about 7 grammes (except in the case of Preparation 4, when the proportions were about doubled). Therefore the solution employed was always considerably in excess of the amount required to dissolve the metal. (All the solutions prepared contained sulphuric acid in the proportion of 0·9 gramme to 1 gramme of the salt; and the strength of the solutions, that is the proportion of chromic acid in the liquids, was checked by an estimation of the available oxygen contained in them.)

The solution used in obtaining Preparation 1 was intended to have been prepared from a bichromate solution saturated in the cold, of the precise nature of that just described; its examination showed however that it was somewhat weaker, being 0·8 the strength of the solution for Preparation 2.

Preparation 3 was produced with a much weaker chromic solution; the strength aimed at was about 0·5 that of Preparation 2, and its actual strength was 0·44.

The chromic liquor used for obtaining Preparation 4 was prepared by mixing a hot solution of bichromate with the requisite proportion of sulphuric acid (1 of the former to 0·9 of the latter); and the strength aimed at was double that of Preparation 2. Two different quantities of the liquid were prepared, but in both cases the strength exceeded that of Preparation 2 by about one-half only (being 1·44 of its strength in one case and 1·65 in the other); a little chromic acid having in each case crystallised out, together with the potassium bisulphate, on the cooling of the liquids.

The mode of treatment of the steel by the chromic solutions was in all instances alike. The solvent (1000 c. c. in this particular case) was contained in a capacious, somewhat tall, glass vessel; and the weighed piece of sheet steel was supported, at about the centre of the liquid, upon a diaphragm, or sieve, of platinum-wire gauze. Though the surfaces of the steel were perfectly cleaned, as described, it would remain quite unattacked in the liquid, even for days, if simply immersed and left at rest; but the action was started at once by moistening the steel with the chromic liquor and exposing it to the air in that state for a minute or two before immersion. By supporting the small platinum sieves upon funnels immersed in the liquids, the heavy solution of ferric sulphate passed down through the funnel as produced, and thus a continuous circulation of the solvent was promoted.

Preparation 1.—Four pieces of the sheet steel (from 7 to 7·5 grammes each) were exposed in separate vessels to the action of the solvent described. After the lapse of two days, there only remained small quantities of a grey-black powder upon the sieves; this was washed off into the chromic liquor, and, together with the powder which had collected at the bottom of the vessel, was allowed to remain from 8 to 14 days in the liquor, the time varying with the date at which the several experiments had been commenced. In every case there was found to be a considerable excess of chromic acid in the solution. The four deposits were afterwards transferred to one vessel; 500 c. c. of fresh chromic liquor were placed upon the combined product, which was allowed to remain in the solvent for four days at the ordinary temperature. During this time no reduction of chromic acid took place. The heavy grey-black powder, which

was strongly attracted by the magnet, was then washed, first with water several times, then with alcohol, finally with ether, and was afterwards dried over oil of vitriol in a rarefied atmosphere until it ceased to lose weight. The amount of dry residue, or carbide, obtained in these operations was 13·25 per 100 parts of steel.

To ascertain the proportion of carbon in this carbon-iron product, the method of treatment by solution of copper chloride was first resorted to; but the substance was attacked with difficulty by the solvent, there being no action at the ordinary temperature even after the lapse of 24 hours.* It was therefore necessary to keep the solvent heated, to promote its action, and this may have given rise to some slight formation of carbo-hydrogen, tending to reduce the proportion of carbon found. Moreover, this carbon, when the action was completed, was obtained in so very finely divided a condition, that its collection without mechanical loss was a matter of some difficulty. For these reasons this method of analysis was abandoned, and the comparatively simple process was adopted of placing and weighing in a small porcelain boat the dry material to be analysed; enclosing this in a Bohemian glass tube; burning in a slow current of dry oxygen; allowing the products to pass over heated cupric oxide; and finally absorbing and weighing in the usual manner the carbon di-oxide and water obtained. At the close of the operation the residual iron oxide in the boat was dissolved in chlorhydric acid, and the iron estimated.

By the copper-chloride process, the percentages of carbon found in Preparation 1, in two experiments, were 6·83 and 6·69. The iron estimated in the liquids (after precipitation of the copper by electricity) amounted in these two experiments to 91·29 and 92·16 per cent.

By the combustion process, the following percentage results were obtained:—

Carbon	7·31
Iron	90·42
Water	2·37

In order to ascertain what proportion of carbon this product would leave unconverted into carbo-hydrogen by treatment with chlorhydric

* This circumstance afforded additional proof that metallic iron had been completely removed by the chromic treatment.

acid, from 0·5 to 1 gramme of the carbide was heated upon a water-bath with excess of the acid (sp. g. of the acid, 1·10): the portion remaining undissolved was collected upon asbestos (previously ignited), washed successively with cold water, cold alcohol, and warm ether, then dried by heating in a current of hydrogen, and afterwards burned in a current of oxygen. In two experiments the carbon unconverted into hydrocarbon amounted to—

1·410 per 100 of the carbide, or 19·29 per 100 of carbon in the carbide.
1·238 „ „ or 16·93 „ „ „

Preparation 2.—Two pieces of steel, weighing about 7·5 grammes each, were treated with the particular chromic solution above described, 1250 c. c. of liquid being used in each case, and the treatment carried on for four days. The two products, of the same nature as those constituting Preparation 1, were then transferred to one vessel, and left for two more days in contact with 250 c. c. of fresh chromic liquor, which appeared unaltered at the end of that time. The amount of carbide which this treatment furnished was 14·16 parts per 100 of steel. The analysis of the dried product by the combustion process furnished the following percentage results:—

Carbon	7·21
Iron	90·64
Water	2·27.

The carbon remaining unconverted into hydrocarbon, by treatment of this product with chlorhydric acid, amounted to—

1·269 per 100 of the carbide, or 17·60 per 100 of carbon in the carbide.

Preparation 3.—Two pieces of steel, weighing about 7·5 grammes each, were submitted in separate vessels to the action of 2000 c. c. of the solution already described (the comparatively weak chromic liquor) for five days. The united products were afterwards left for five days in 500 c. c. of fresh chromic solution, which did not appear at all affected. The amount of carbide obtained from 100 parts of steel was 15·34. The percentage results obtained in three examinations of the product were as follows:—

Carbon	6·84	6·84	
Iron	91·53	91·50	91·50
Water	1·63.		

The carbon unconverted into hydrocarbon by treatment of the carbide with the chlorhydric acid amounted to—

0·836 per 100 of the carbide, or 12·22 per 100 of carbon in the carbide.

Preparation 4.—Here 14·7 grammes of the steel were exposed for three days to the action of 1900 c. c. of the chromic solution described (the strongest solution), and the product obtained was afterwards left for four days in contact with 350 c. c. of fresh solution, which appeared but very slightly affected at the end of that time. The amount of carbide obtained from 100 parts of steel was only 4·66. It was found to have the following percentage composition:—

Carbon	11·77
Iron	80·57
Water	5·57

There was not sufficient material for a repetition of the analysis, nor for ascertaining the proportion of residual carbon after treatment with chlorhydric acid.

For comparison, the amount of carbon unconverted into hydrocarbon, by treatment of the original steel with chlorhydric acid, was determined, and found to be—

0·039 per 100 of steel, or 3·41 per 100 of carbon in the steel.

Table A (p. 65) is a tabulated view of the results obtained in these four series of experiments.

An examination of the foregoing results suggests the following observations:—

1. The two chromic solutions used for the production of Preparations 1 and 2 (which differed but little from each other in regard to the amount of chromic acid present, and were produced with a bichromate solution saturated, or nearly so, in the cold), furnished results in all respects very similar, though the details of treatment of the steel with these solutions differed somewhat. The third, a much weaker solution, furnished results which, allowance being made for the small quantities of products to be dealt with, and the difficulties of their analytical examination, must be regarded as closely resembling those obtained with the other two solutions.

TABLE A.—RESULTS OF TREATMENT.

	Preparation 1.	Preparation 2.	Preparation 3.	Preparation 4.
Carbide obtained per 100 of steel	13·25	14·16	15·34	4·66
Composition per 100 of carbide—				
Carbon	7·31	7·21	6·84	11·77
Iron	90·42	90·64	91·53	80·57
Water	2·37	2·27	1·63	5·57
Atomic Ratio of iron to carbon	2·65 Fe to 1 C	2·694 Fe to 1 C	2·867 Fe to 1 C	
*Parts of carbon obtained in form of carbide per 100 of steel	0·969	1·021	1·049	0·266†
Carbon unconverted into hydrocarbon by treatment of carbide with chlorhydric acid—				
Per 100 parts of carbide .	1·410 1·238	1·269	0·836	
Per 100 of carbon in the carbide	19·29 16·93 (Mean 18·11)	17·60	12·22	

* Had the chromic treatment given rise to no formation of hydrocarbon, the amount of carbon obtained as carbide should have been 1·144, that being the total amount of carbon in this steel.

† In this case, the number is arrived at by calculation from the amount of iron found in the residue, the carbide being assumed to have the composition Fe_3C.

2. The results obtained with the stronger chromic solution (Preparation 4) indicate that the limit of the concentration of oxidising power, which the separated carbide is capable of resisting, has here been exceeded. Not only has there been in this case a comparatively very considerable loss of carbon, as carbo-hydrogen (or possibly also as a soluble product of oxidation), but the iron in the separated carbide has also been to a considerable extent attacked; and but a comparatively small proportion of the carbide remains, in admixture with separated carbon, the latter partly in a hydrated form, and possibly also in some partially oxidised insoluble form.

3. The proportion of combined water in the products obtained with Preparations 1, 2, and 3, would seem to indicate that, in these also,

the carbide exists in admixture with small proportions of a carbon-hydrate, which may be a result of the action of the chromic solutions on the carbide first separated. This may possibly account for the not very definite, though on the whole uniform, atomic ratio of the iron to the carbon in the products of Preparations 1, 2, and 3.

4. Deducting the proportions of carbon, unconverted into hydro-carbon by treatment of the products with chlorhydric acid, from the percentages of carbon in the products obtained in Preparations 1, 2, and 3, the results exhibit a uniformity which, if accidental, is somewhat remarkable. Thus:—

TABLE B.—FINAL PROPORTION OF CARBON.

	Preparation 1.	Preparation 2.	Preparation 3.
Carbon in product, per cent. . .	7·31	7·21	6·84
Less Carbon unconverted into hydro-carbon	18·11%=1·32	17·6% = 1·27	12·22%=0·84
Leaving of Carbon, per cent. .	5·99	5·94	6·00

The atomic ratio of this residual percentage of carbon is as 1 to 3·270 of iron.

5. It will be observed from Table A that the amount of carbon, eliminated in the solid form by the chromic treatment, most nearly approaches the total amount of carbon contained in the steel (1·144 per cent.), in the case of No. 3, when the weakest chromic solution was employed—a result which was anticipated. Even in this case the two figures do not approach each other quite as closely as they did in the case of the specimen of cold-rolled steel, referred to in the preliminary report (Proceedings 1881, p. 703); but this may perhaps be in part ascribable to the circumstance that, in the latter case, no search was made for water, in the products obtained by the chromic treatment. It appears conclusively established that, in all instances, some portion of the carbon is expelled as hydro-carbon by the chromic treatment; and that some small and variable proportion of the carbide, separated from the cold-rolled steel by that treatment, is afterwards acted upon, with disappearance of iron and formation of some carbon-hydrate.

6. On the whole, these results, which are in all respects more complete than those obtained in the much smaller and really preliminary experiments described in the former report, appear to afford foundation for the belief that the material separated from cold-rolled steel, by the action of a sufficiently dilute chromic acid solution, contains an iron carbide corresponding or approximating to the formula $Fe_3 C_1$, or to a multiple of that formula. The requirements of such a formula are intermediate between those furnished by the original percentage composition of Preparations 1, 2, and 3, and by the composition of these, after deduction of the proportions of carbon unconverted into hydro-carbon by their treatment with chlorhydric acid.

The results of these experiments with cold-rolled steel of *a particular composition* appear at any rate to confirm the correctness of the view that the carbon in cold-rolled steel exists, not as simply diffused mechanically through the mass of the steel, but in the form of an iron carbide—a definite product, capable of resisting the oxidising effect of an agent which exerts a rapid solvent action upon the iron through which this carbide is distributed.

Whether this carbide varies in composition to any great extent, in different descriptions of steel, which are in one and the same condition of preparation (*i.e.* cold-rolled or annealed), remains to be demonstrated by further investigations, if the determination of this point is considered of sufficient importance to warrant the expenditure of the time and labour which it would involve. The preliminary experiments with small specimens of cold-rolled, annealed, or hardened steel, described last year, appeared to warrant the belief that the condition of the carbide in the metal is affected to such an extent by the process of hardening, as more or less completely to counteract its power to resist the decomposing effect of such an oxidising agent as chromic acid solution. How far this may always be the case, and how far it may be possible to prove that similar effects to a modified extent are produced by the submission of steel to tempering processes in different degrees, may perhaps be determined by further research in this direction.

Abstract of Discussion.

Prof. HUGHES, F.R.S., said he had been very much interested in the reading of this report. Table B showed how remarkably uniform the results had been, so that there could not have been any error whatever of importance in the mode of treatment. There was however a possible source of slight error, though it had in fact produced none, in the using of platinum sieves. He feared there might be an electric current generated by the steel resting upon the platinum. If it were possible to make connection permanently between the two, and in exactly a similar manner for each one of the experiments, they would then have uniform results; but that would be impossible to obtain by simply laying the steel on the platinum. He thought if Prof. Abel could possibly avoid the use of platinum it would be better.

Sir FREDERICK J. BRAMWELL, F.R.S., said he should be glad if Prof. Abel in his reply would touch upon the question, whether they might look upon the condition of carbon in hardened steel as analogous to that of carbon in chilled cast-iron. Cast-iron before chilling contained (to judge by the eye) carbon intermixed as it were with the iron, the flakes being sometimes large enough to be visible; but if chilled it assumed a uniform structure. Did the same reasoning that prevailed with regard to the hardening of iron by chilling prevail with regard to the tempering of steel? In speculating upon the matter, he had often thought that the operation of hardening steel was similar to that of chilling iron,—that the sudden cooling had the effect of preventing the separation from the iron of particles of carbon which would separate out if the cooling were gradual; and that in that way such particles were retained permanently within the iron, either as a chemical compound or as an alloy. But it had occurred to him that, if that were so, it might perhaps be possible to attain the same result, in steel or in molten iron, by subjecting it to violent agitation during the whole time the cooling was taking place,—letting the cooling itself be gradual, but

allowing the agitation to go on the whole time. He had in his mind what happened with certain mixed liquids. If they were allowed to cool gradually, they would separate out from each other; but if they were stirred during the time of cooling, uniformity of mixture was obtained, and separation was prevented. It seemed to him that, if the true effect of chilling molten cast-iron or of hardening steel was to prevent the separating out of particles, then probably—he did not at all say certainly—the same result might be obtained by agitation; and in that way one might as it were by another process check the conclusions arrived at by chemical analysis.

Professor ABEL, C.B., F.R.S., said that, before answering the questions which had been put, he thought a word of apology was perhaps due for the fact that the substance of the report had so little immediate reference to the professed subject of the Committee's researches, namely the Hardening of Steel. That was simply due to the fact that a research of this description necessarily involved a very considerable amount of preliminary work, before the foundation for a course of experiments could be firmly established; and all that the present report could pretend to do was to establish such a foundation for an examination into the difference between steel in the annealed, in the hardened, and in the tempered conditions. He hoped the results, so far as they had gone, warranted the belief which he now entertained, that he had established a method of examination, by which he might compare the chemical characters of different portions of one and the same description of steel, when submitted to different processes of hardening and tempering, with a good chance of obtaining some little insight into the effects which those various treatments produced.

With regard to the very pertinent remark of Prof. Hughes, he might state at once that the fact that electric action would be established between iron and platinum, immersed in a chromic solution, had not been overlooked by him in the experiments; but although there would thus be variations in the action, as Prof. Hughes had correctly pointed out, in consequence of the impossibility of having exact similarity in the points of contact in the various

experiments, still he had considered that this would not affect directly the ultimate result of the action of the solvent upon the metal; and he thought such had been proved to be the case by the uniformity in the results that had been obtained. If it were possible to substitute for the platinum, in future experiments, some material which should be absolutely inert, he should be only too glad to avail himself of such a resource. It was somewhat difficult to find a method of experiment, by which the various samples could be submitted, as uniformly as possible, to one and the same chemical treatment. It was desired by the use of a sieve, which could not be acted upon by the chromic solution, to obtain an arrangement by which the fluid might freely circulate round the metal by convection, during the course of the chemical action, which went on for several days; and if he could find some material which was quite without any relation, electric or otherwise, to the metal immersed in the chromic solution, it would be very valuable in future experiments.

With regard to the question raised by Sir Frederick Bramwell, he could only venture to offer a very guarded opinion. He confessed that he had always regarded the condition of carbon in chilled iron as analogous to the condition of carbon in hardened steel; and so far as the chemical comparison of the two materials went, it would appear as if the sudden arresting of the effect of heat, or the sudden bringing down from a highly heated to a comparatively cold condition, of the mass of the material, whether it was cast-iron or steel, had an analogous effect upon the condition of the carbon in the cooled metal. There was of course this important difference between the two cases which they were considering, that in the case of cast-iron they were acting upon the substance in the fluid condition, whereas, in the case of hardened steel, they were acting upon it in the solid condition. How far that important element of difference affected the result might perhaps be shown to some extent by the experiments upon which the Committee had embarked, if they had the courage to continue them sufficiently far.

In reference to the subject under consideration, it was right that he should refer to some interesting experiments, with which no doubt many members were already acquainted, made by M. Clemendot. In

these, by subjecting red-hot steel to a powerful pressure, very similar results had been obtained, as far as regarded the physical characters of the product, to those produced by hardening and tempering; and it was claimed for that particular method of treating steel that, while it could impart to steel a degree of hardness and a variety of temper similar to that which was given by ordinary hardening and tempering processes, it produced an effect which was permanent, and was not subsequently modified by considerable variations of temperature. He himself thought the results, as far as he had seen them, had certainly some promise; and it was intended to make some experiments at the Arsenal (upon which in fact they had already embarked), with a view of ascertaining whether M. Clemendot's statements were really borne out in actual practice.

The PRESIDENT said he had pleasure in calling upon the members to give a very hearty vote of thanks to Prof. Abel for the patient and excellent manner in which he had carried out the experiments so far, and for his valuable record of those experiments. He was sure they would all express with him a hope that Prof. Abel would conduct these experiments to their full issue.

Prof. ABEL said, in thanking the members, it was only right that he should say that the greatest measure of thanks was due to the gentleman who had performed the experiments in connection with the research; for the experimental portion of the work was the most laborious, painstaking, and tiring of the whole. He felt that without the valuable assistance of his colleague, Mr. Deering, it would have been impossible for him to bring forward even the few results in which he had endeavoured to interest the members of the Institution.

ON THE MOLECULAR RIGIDITY OF TEMPERED STEEL.

BY PROF. D. E. HUGHES, F.R.S.

During the course of some recent researches the writer has been enabled, by the aid of the induction balance, to perceive some remarkable molecular differences between the constitution of iron and of steel.

There are numerous papers in the 'Comptes Rendus,' from 1830 to 1850, in which it is suggested that tempered steel is a true alloy of iron and carbon, the carbon being present in varying degrees according to the temperature at which the alloy was formed, and being afterwards rendered permanent by sudden cooling.

In a late discussion on this subject * the writer made a few remarks, in which he pointed out the marked difference between softened and tempered steel, as to solubility in dilute sulphuric acid, and expressed the opinion, formed from these and many previous experiments, that tempered steel was a true alloy.

He has since continued these experiments, not however to prove the chemical composition of tempered steel, but to investigate its peculiar molecular structure, as indicated by the induction balance.

The apparatus necessary to perceive the effects of stress or torsion, as described in this paper, is exceedingly simple. Suppose, for instance, that we take an ordinary single-coil electro-magnet, and join its terminals with those of a telephone or sensitive galvanometer. If we now pass a current from a battery through the iron core alone of the electro-magnet, we have a sharp click at each make and break of the current. This effect was discovered by Page, and fully described by De La Rive.†

If we keep the current passing constantly through the core, we have no effect; but if we then give a slight torsion or twist to the

* Proceedings, 1880, p. 233.

† De La Rive, Treatise on Electricity, vol. I., chap. v. London, 1853.

core, either to the right or left, we at once hear a sharp click; and if we keep the torsion constant, and then make frequent interruptions of the battery, we have a greatly increased sound at each make or break, indicating a greatly increased force of electric current.

In order to investigate this phenomenon, the author constructed a special though very simple apparatus, shown in the sketch, Fig. 1, Plate 1.

A coil A, having a large aperture, is fixed to a board; two small abutments or supports, B and C, at a few inches' distance from each end of the coil, allow us to suspend or fix an iron or copper wire passing through the aperture, which then becomes the core of an electro-magnet. This forms the essential portion of the apparatus. The wire rests upon the two supports, which are 20 centims. apart; at one of these, C, it is firmly clamped by a binding screw, while the opposite end at B can turn freely. The wire is 22 centims. long, projecting 2 centims. beyond its support. On the projecting end is an arm D (with its binding screw E), which serves as a pointer moving on a graduated circle, and gives the degree of torsion which the wire may receive. A binding screw F allows us to fasten the arm, after turning the pointer to any degree of torsion, and thus preserves the required stress as long as is necessary.

The exterior diameter of the coil is 5½ centims., and that of the interior vacant aperture 3½ centims.: the width is 2 centims. Upon this coil is wound 200 metres of No. 32 silk-covered copper wire. This coil is fastened to the board by a screw S, so that it can be turned through any desired angle in relation to the wire which passes through its centre; and it can also be moved so as to lie over any portion of the 20 centims.' length of wire, in order that different portions of the same wire may be tested under a similar stress.

The whole of this instrument, as far as possible, should be constructed of wood, in order to avoid all disturbing inductive influences of other pieces of metal upon the coil.

The iron wire at its front end B is joined to or makes contact with a copper wire, which passes to the rear end C along a groove in the board GG, parallel to the coil, thus forming a loop. The rear end of the iron wire at C is joined to one pole of the battery; the

copper wire, after passing along the board, is joined to a rheotome, and thence to the other pole of the battery. These junctions are effected by the binding screws H and K respectively.

The coil is joined to a telephone or a sensitive galvanometer; and we may either pass the current in the manner described, or may reverse all the communications, passing the current through the coil instead of through the wire, and listening with the telephone to the induced currents upon the iron wire alone.

In order fully to understand the phenomena which take place, we must bear in mind Faraday's discovery of electro-magnetic induction:—namely that any wire conveying an electric current induces in general a momentary secondary current in any independent circuit whose wires are parallel to it; the effect being at its maximum when the two wires are parallel, diminishing as the angle of these wires is increased, and at 90° being absolutely zero. Consequently, when we place a copper wire in the axis of the coil, with the above apparatus, and pass a current through this wire, we find no effect whatever, no trace of induced currents; simply for the reason that this copper wire crosses all the wires of the coil at an angle of 90°. We also find that no effect takes place upon torsion being applied to the copper wire. If we now place a small rod of iron parallel with the conducting copper wire, we have no effect; but if the iron rod is turned at an angle to the conducting wire a current is observed, the force increasing from parallelism to an angle of 45°, and decreasing again from this angle to 90°, where we have again no effect. The conducting copper wire thus induces electric magnetism in the iron rod, and this magnetism reacts upon the coil; but this only holds as long as the rod is not parallel either to the conducting wire or to the coil. At an angle of 90° to the conducting wire, although at its maximum of electric magnetism in relation to that wire, the iron rod becomes parallel to the coil upon which it reacts; consequently we have again a zero of current. In place of one rod, we may insert several short rods, and if these are all turned together in the same direction, we have similar effects.

Knowing this, we can understand that if each molecule of a rod were endowed with separate magnetic power, and if we could cause

these to rotate through any angle round the axis, we might expect similar reactions to those of the small separate iron rods already mentioned.

If now we replace the copper wire spoken of by an iron wire, and send intermittent currents through this, we still have no induced current upon the coil; but the instant we apply a very slight torsion to the arm D, say 10 or 20 per cent. of one turn, we at once perceive strong induced currents. These are positive for right-hand torsion, and negative for left-hand torsion. Thus we can not only produce induced currents, but, without changing the direction of the primary electric current, we can change the induced currents, making them positive or negative as we please; exactly as would occur if we rotated in opposite directions the small iron bars, placed side by side with the copper wire.

At this point it becomes important to know if these effects are produced by the twist given by torsion to the whole mass of the wire, or if each molecule turns separately and independently round its axis. There are many proofs that the latter view is correct. For, assuming the former, then, if an iron wire be twisted permanently by thirty or more entire turns, we should expect greatly increased effects as compared with those given by 10 or 20 per cent. of a single turn. But we find that after the first instant of torsion we have no increase of force in the current, even with a molar twist of 30 whole turns, which must of course produce a certain molecular twist; and again we find that the slightest torsion backwards, say 10 per cent. of a single turn, is sufficient to reverse the current, and thus more than neutralise the whole inclination which had been given to the molecules by the permanent torsion of 30 entire turns.

These effects are represented to the eye in Figs. 2–5, Plate 1. In Fig. 2 the small arrows indicate the supposed positions of the molecules, when initially at rest; in Fig. 3 we see the change in direction produced by a slight torsion; in Fig. 4 the similar position after a torsion of several complete turns; and in Fig. 5 the reversal of the inclination on a slight release of the former twist.

Again, if, whilst the iron wire is under the influence of torsion, we bring near it one pole of a large natural magnet, laid in the

direction of the wire, we find that the currents gradually diminish, until when the magnet touches the wire there is at last no current at all. The polarised molecules, which under the influence of torsion lay at a certain angle with the axis, have thus been caused to rotate back again, and become parallel to it. Again, if we bring the same pole of the magnet near to the wire, but at right angles to it, we find that the current gradually returns to zero (and therefore the molecules to parallelism) when the magnet is about two inches distant; but on bringing the magnet still nearer, it passes the zero point, and now becomes a reversed current of increasing strength, until it reaches a maximum when the magnet is close to the wire. We have thus rotated the molecules from their original angle of torsion, say of 45° to the right, through zero to 45° to the left. If this view is correct, we should expect that we might produce electric currents of reversed directions without the aid of any battery, by simply giving a to and fro torsion to the wire; and this proves to be the case. For we may join the telephone either to the exterior coil or to the simple circuit of the wire, and we shall then hear a sharp click at each movement of torsion to the right and to the left; thus imitating and reproducing all the effects which would be obtained by rotating a separate magnet through different angles of inclination to the wire.

There are many proofs which confirm this view *; but as the object of the author is to show the remarkable difference which exists between iron and steel in this respect, he will confine himself to showing the very great apparent rigidity of the molecules of tempered steel as compared with those of iron.

A very remarkable difference appears when we turn to tempered steel. For here we find that at certain degrees of temper (*e.g.* that known as blue or spring temper) there are only slight traces of molecular disturbance or rotation, no matter how many mechanical turns or twists we may put on the wire. In fact, the molecules here seem fixed and homogeneous throughout the mass. We have perfect molar elasticity, but no traces of rotation of one

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* *See* Molecular Magnetism, by Professor D. E. Hughes. Proceedings of the Royal Society, March 7 and 17, and May 10, 1881.

part over another—in other words, no molecular elasticity. This is indicated, as before, in Figs. 6–8, Plate 1; where Fig. 6 shows the position of the molecules at rest, Fig. 7 after slight torsion, and Fig. 8 after great torsion—their direction remaining very nearly parallel throughout. Thus in iron we have an elasticity due solely to the freedom of molecular motion. In hard steel, on the contrary, we have but slight molecular freedom, with great molar elasticity, the separate molecules rotating not separately but all as one mass.

It is necessary to point out this difference of molar rigidity, as shown in tempered steel and in iron, because tempered steel is not the only form which thus differs in its mechanical and physical qualities from iron or soft steel. A similar difference is shown also by several known alloys of iron.

We can diminish the apparent rigidity of steel by the application of heat; for if we pass a constant and powerful current through the steel wire, which previously gave but feeble traces of molecular rotation, and then heat this wire to red heat, a strong induced current is gradually produced. The current here has the power of rotating the polarised and heated molecules, and so giving out comparatively strong induced currents. But on cooling this wire it is impossible again to reduce it to silence. The molecules remain rigid, but at an angle to the axis. With iron however, upon the application of heat under the same circumstances, we have a most violent rotation, which entirely disappears on cooling—proving again the great comparative freedom of its molecules.

We might believe that all the above effects in steel are due, not to the rotation of the molecules, but to the more or less retentive or "coercitive" force of steel with regard to permanent magnetism. But coercitive force, whilst it may suffice to explain, according to accepted views, the retention of magnetism, does not explain why we can produce positive and negative currents by right- or left-handed torsions, nor why we should produce induced currents by torsion. If we accept the term coercitive force as simply applicable to each molecule, then we have still to consider the greater freedom of motion of these molecules in iron than in steel. It is a general belief (which the author has hitherto shared) that the molecules of tempered steel have far

greater coercitive force than those of iron. A simple experiment will however prove this not to be the case. For if we suppose that the molecules of iron turn with far greater freedom, it follows that they should also turn by the application of far less force. Now if we take a soft iron and a tempered steel wire, and place them at a given distance from a suspended magnetic needle (after finding them both to be free from magnetism), and if we then magnetise these wires by drawing them over the poles of a natural magnet, then we may no doubt find as usual that the tempered steel has a far greater amount of remaining magnetism. But if, instead of this, we limit the reactive force of the natural magnet, by placing a piece of wood, say $\frac{1}{2}$ in. thick, between the magnet and the wire to be magnetised, thus limiting and controlling the magnetising force to any degree according to the distance between the magnet and the wire, we then find, on magnetising the same two wires with a weak reactive force, and again observing their action upon the needle, that the soft iron still shows powerful retentive or coercitive force, whilst the tempered steel has but feeble traces of magnetism, or none at all. Thus, contrary to the author's previous convictions, it appears that *iron possesses more coercitive force than steel whenever the inducing force is limited, and within the range of iron.*

If iron merely possessed greater coercitive force than steel, it would be impossible for us to employ soft iron in electro-magnets requiring quick changes of magnetism. But although, in the previous experiment, the remaining magnetism was far greater in the iron than in the steel, yet the magnetic force of the iron, whilst under the influence of the permanent magnet, was some twenty times greater than its remaining magnetism; whilst with the steel there was but a slight difference in the force developed whilst it was under the feeble influence of the natural magnet, and after this was withdrawn.

Assuming the freedom of motion of the molecules to be greater in iron than steel, it occurred to the author that he should be able to free the soft iron from its remaining magnetism by simple vibration of the wire. This was found to be the case. An iron and a steel wire are magnetised to saturation; or both may be given the same amount of permanent magnetism. We will suppose that they both deflect

the suspended needle through 40°. Now taking the steel wire and fastening one end in a brass vice, give its free end a slight pull to set it in vibration: it will be found that the steel has lost but 2°, having still 38° of permanent magnetism, which cannot be further reduced by repeated vibrations. The instant however that a similar vibration is given to the soft iron wire, its remaining magnetism nearly all disappears; there is left at most 2°, or in some cases only a trace. Thus the molecules are seen to be comparatively so free in iron that mere vibration will aid them in rotating. These two wires were again observed vibrating whilst under the influence of the permanent magnet. There was then a greater magnetic effect produced in the iron wire than previously; the vibrations aiding the rotations produced by the natural magnet.

The author was desirous to render visible this freedom of iron and rigidity of steel, so that these effects might be actually seen. For this purpose we may take three glass tubes, or ordinary phials, of any length or diameter, say 10 centimetres in length by 2 centimetres in diameter. If we now put iron filings in these tubes, leaving about one third vacant, so as to allow complete freedom in the filings when shaken, we find that each tube, when magnetised, retains an equal amount of residual magnetism, and that this all disappears upon slightly shaking the tube; we are thus imitating the effects of vibration. But if into one of these tubes we pour melted resin (or in fact any slightly viscous liquid, such as petroleum, suffices), we then render these filings more rigid, and now we can no longer by shaking produce the disappearance of its residual magnetism. By pouring in petroleum we have apparently been introducing a strong coercitive force; but we know that it can only have the mechanical effect of rendering the iron filings less free to turn, and so comparatively rigid. If we desire to see the effect of torsion, we have only to shake the filings so that when the tube is held horizontal the vacant space is above, and then rotate slightly (but without shaking) the tube containing the free filings about a horizontal axis. Its remaining magnetism instantly disappears upon rotation, although evidently we have not changed the longitudinal position of its particles. A similar effect takes place upon a soft

iron wire; for if we magnetise it and observe its remaining magnetism, we find that upon giving a slight torsion to this wire, its remaining magnetism instantly disappears—just as in rotating the tube of iron filings.

The author has remarked in these researches that in all alloys of iron the molecules are far more rigid than in the pure metal; and further that, with steel, tempering adds greatly to this rigidity. He is now engaged upon the question of the effect of different tempers on the same steel, and hopes in a future paper to be able to bring the results before the Institution.

A comparison of soft steel with hard drawn iron shows that the mechanical hardening of iron has not in any great degree diminished its molecular freedom. Even the softest steel shows a high degree of molecular rigidity, as compared with the hardest iron; but far less than that of tempered steel. This would seem to indicate that steel in its softest state is still an alloy, though only feeble quantities of carbon may be held in that condition.

We thus perceive that a great physical change takes place in iron upon the slightest alloy with carbon; and that tempering produces this change in its highest degree. The writer therefore is strongly in favour of the view propounded long since, that steel when tempered is an alloy, containing fixed carbon in a far greater quantity than when soft. We know the physical properties of magnetic oxide of iron, of iron and tungsten, and of iron and sulphur. Now in all these the writer has found that the iron loses its molecular freedom when even slightly alloyed. The physical results are therefore the same as those produced in tempering steel; and the induction balance thus indicates strongly that tempered steel has the characteristics of a true alloy.

We could not have such a great physical difference between iron and steel, as above noticed, except by corresponding changes in their mechanical properties; and it is with a view of bringing out these relations in a discussion on this point, that the author has ventured to bring his views before the Institution of Mechanical Engineers.

Abstract of Discussion.

Prof. HUGHES, F.R.S., said he had prepared some experiments to render visible some of the effects which they had heard described in the paper. All these experiments had been simply taught him by the induction balance. They might be described as gross mechanical imitations of what would be seen passing in an induction balance if it could be magnified sufficiently. When he first invented and brought out that instrument, he thought it would be capable of analysing metals, and determining the chemical character of the alloys of all metals. For that purpose Prof. Roberts associated himself with him in testing the coins made at the Mint by the induction balance; but they found that if they took two shillings of exactly the same chemical composition, of exactly the same weight, and exactly the same in every external appearance, there would still be a difference in the result; and that result was always due to some molecular change,—not a chemical, not a mechanical change, but a molecular change. That change often appeared to be far greater than any conceivable chemical change that could take place in any alloy; and the consequence was the induction balance could not be used for a chemical test, although it was excessively sensitive to any change in chemical condition, provided the molecular conditions were kept the same. It was a very extraordinary thing that they could scarcely ever find two shillings, though cut from the same piece, which were exactly the same; but by testing several thousand shillings they did at last find two, which were very valuable because they were exactly the same. At that time he had been particularly desirous to investigate the chemical question, but the molecular structure was always interfering; the balance would not indicate anything but the molecular construction. If he took a piece of iron, or any other metal, and put it in one balance, it was exceedingly difficult to find another piece of iron, although cut off the same piece, which if put into the other would quite balance it. Moreover if there was the slightest change made, by hammering or otherwise, in one of the pieces, the balance was upset immediately; so that it indicated at once all the changes which took place through molecular actions. He had

thought a great deal upon these points, and he became so interested in the molecular changes that at last he no longer saw the body itself—the shilling or the iron; he was always looking at the molecules, his mind's eye was altogether upon them. If therefore, in speaking on the subject of molecular motion, he took for granted his hearers knew all about it, they would excuse him; because he was so used to thinking about those points that he might perhaps take some things for granted that were not so well known to others.

The induction balance was not suitable for measuring iron, from the very difficulty of producing a perfect balance. He had found a peculiar effect in iron, which existed in that metal alone. If he had previously balanced one piece of iron with another, so that they weighed exactly the same in the induction balance, then the slightest torsion, applied to one piece, would cause the balance to be upset completely. On investigating that further, he found that if he took a coil and put an iron wire inside that coil at right angles to it, and passed a current through the wire, then it did not produce any effect; but if he turned the coil so as to be at any other angle with the wire, an effect was produced. But with iron (not with other metals), if the very slightest torsion—so slight that you could not perceive it with the eye—were given to the wire when at right angles to the coil, immediately, as if a door were opened, loud tones were heard in the telephone. If the coil were then set at a certain angle to the wire, there was silence, and the arrangement was balanced again. If the wire were twisted the other way, the coil must be turned round to the other side, and then there would be silence again. Hence something must have been rotated inside the wire. Investigating the matter further, he found that if, instead of turning the coil, he took a bar of iron and placed it beside the wire, but at a certain angle to it, he could produce silence with right-hand torsion of the wire; and similarly with left-hand torsion, if it were set at an angle in the opposite direction. He had been asked what proof there was of the actual rotation of the molecules. That was one proof, and there were many others, enough to form the subject of a paper. But as he wanted to get at something practical, he would take the rotation for granted, and simply show its effects in a practical case.

Now in the induction balance the effects were entirely produced by electricity. The passage of a current through the wire induced electro-magnetism in the molecules, and that re-acted upon the coil. What he proposed to do that evening was to imitate these electric effects by magnetic effects. For this purpose he used a parallel row of little magnets, such as in Fig. 9, Plate 1, attached to a sort of parallel ruler. If he passed a current through the wire, and then shifted the magnets backwards and forwards, he produced the same effect as when he twisted the wire. When the magnets pointed north, a galvanometer-needle turned one way; but when they pointed south it turned the other way, and instead of the magnets attracting the needle, they now repelled it. [Experiment shown.] In order to show these effects, he had provided a needle consisting of two knitting needles put together, simply to demonstrate by attractions and repulsions the effects of magnetism. In order that it might swing free, it was hung by a loop of wire; but in order that it might stop as quickly as possible, two stops or projections were placed, so that it could vibrate only towards one side. Again, if he wished to demonstrate the polarity of any piece of iron, he might use the same needle. If the iron were perfectly neutral, the needle would be attracted equally by its north or south pole, and that would be a proof that it was not a magnet. If however repulsion were produced by approaching one end to the needle, then that end must be a pole, and a like pole to the end of the needle which it approached. [Experiment shown.] The only true test in those matters was repulsion; attractions might be neglected, because they were a proof only of the softness of the iron.

The paper had described other results with bottles of filings. He had conceived the theory that steel molecules were extremely rigid, so that they could not be easily turned, and therefore steel retained its magnetism exceedingly well; while in iron the molecules were very free to turn. During his experiments, it occurred to him that iron filings would similarly keep their magnetism if made rigid, and that they would lose their magnetism if set free. He had therefore taken two bottles containing exactly similar iron filings: in the one case they were kept rigid by pouring in resin, and in the

other case they were free. The first kept its magnetism, and became a permanent magnet; the other lost it immediately. In the bottle with the resin, by drawing it across a permanent magnet, it was thoroughly magnetised, and repelled the needle; so that the molecules were all turned or polarised; and it would be seen that the repulsion was still there after any amount of shaking or beating of the bottle. [Experiment shown.] He would now try the same experiment with the filings that were loose. They were magnetised in the same manner, and it would be seen that there was a strong repulsion on the needle. That state would remain for days and weeks—in fact it would never disappear—if the bottle were not shaken. But if it were once shaken, the magnetism entirely disappeared. [Experiment shown.]

It was natural to suppose that, in shaking the bottle, in some mysterious way he acted upon certain magnetic fluids, shaking the north fluid up to the south fluid, and so mixing them together. But, instead of shaking the bottle of filings, he would simply lay it horizontally, and roll it round slightly. That rolling could not mix up the north poles and south poles, but would simply allow the molecules to turn over themselves; yet it would be seen that, just as before, the magnetism was all gone and there was no attraction. [Experiment shown.] In that case those present knew from the evidence of their own eyes that the particles were loose; but they might all doubt whether the molecules were equally loose in a piece of iron. He would repeat the same experiment with a piece of iron, and they would see precisely the same effect; the slight jarring produced by a single tap of the iron upon the table was sufficient to destroy its previously acquired magnetism. He would then take a piece of steel and magnetise it, and it would be seen that, after any amount of jarring or vibration, there was always a strong repulsion of the needle; showing that the magnetism was still there, and that the molecules could not turn. [Experiments shown.]

Again, it had been supposed by many persons, as the paper stated, that steel retained much more residual magnetism than iron; but this was only true when the proportion of force was beyond the limits of the iron. Taking a weak force to magnetise both, the iron

would be found to retain a great deal more magnetism than the steel. He had before him for this purpose a magnet, and a little piece of wood arranged in steps, for placing upon the magnet so as to try different magnetic forces. By rubbing the iron or steel on the magnet, with different thicknesses of wood interposed, different degrees of magnetic force were obtained. With about half-an-inch thickness, the force was not sufficient to magnetise steel; it would not move the needle. But on magnetising iron with the same thickness of wood interposed, they would see that the iron had a strong remaining magnetism. If he went a step lower in thickness, he might get enough magnetism in the steel to move the needle, but it would still be excessively weak, while it would be much stronger with the iron; but if he went down to the bare magnet, then the magnetism with the steel was very strong, and perhaps stronger than with the iron. [Experiments shown.]

In all the experiments with the induction balance, he had noticed that vibrations or jarrings were very powerful in producing molecular changes; but nothing produced such complete and instantaneous effects as torsion, and he could conceive the reason; namely because it rotated all the molecules equally and at once. He now wished to show whether torsion produced similar effects with this apparatus. Taking a piece of magnetised steel, it produced a strong repulsive effect on the needle; and however much he twisted it, it always repelled. But taking a piece of iron (with a piece of brass interposed, so as not to touch it), this, if strongly magnetised, repelled violently; but he could destroy the magnetism by a slight torsion, and then, instead of repelling, it would become so soft that the needle would follow it. [Experiment shown.] It might be thought that he had put such a force on the piece of thin soft wire that he had torn the fibres. But if he took a piece of stout iron rod, and magnetised it so that it became an extremely powerful magnet, yet after a very little torsion there was no longer any repulsion, and it attracted. [Experiment shown.] He would now try the same experiment as the last, but with a piece of cast steel. One end was tempered, and the other was hard drawn. He might be able to get rid of the magnetism at the untempered end, but he did not think it possible; certainly

he could not at the tempered end. [Experiment shown.] It would be seen that after the torsion each end was still a strong magnet. The reason was, in his opinion, because steel was an alloy; and the question was whether tempering could produce that change only because the steel was an alloy, or whether tempering *per se* produced it. He had noticed that, if iron were beaten hard, it had a great power of retaining magnetism; and Prof. Abel had remarked with regard to condensed steel that it was very good for retaining magnetism. He could conceive that a piece of iron might be condensed so hard that the molecules could no longer turn; and whenever the molecular rigidity became great enough, it would retain its magnetism for ever, because the molecules could not turn. He held in his hand a piece of ordinary nickel which he would magnetise. He would then put it in vibration, and the result would be seen to be that the magnetism instantly disappeared. [Experiment shown.] He had another piece tempered by being heated red-hot and plunged in water. It was strongly magnetised, and it would be seen that like the former it would not stand any vibration without losing its magnetism. [Experiment shown.] Thus nickel (and the same was true of copper, &c.) was softened, not hardened, by tempering; which was another proof, to his mind, that an alloy of carbon was necessary to enable a metal to harden when tempered by quenching.*

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* All non-magnetic metals, such as copper, brass, &c., become softer by tempering; cooling, whether rapid or slow, having equally an annealing effect, though slow cooling is the more efficacious.

Even iron, when chemically pure, becomes softer by tempering; but iron, when in alloy with sulphur, phosphorus, silicon, tungsten, and above all with carbon, becomes harder when cooled suddenly. Thus it would appear that the real effect of tempering *per se* is to soften a metal; but when we have produced a high alloy of carbon by means of a high temperature, we may fix that alloy by sudden cooling.

The result, in the case of iron and carbon, is the extremely hard metal known as tempered steel: and even this would probably have been still harder, but that the effect of the tempering itself has operated to soften the metal to some extent. Thus the effect of tempering would seem to be due to the permanent maintenance of a particular alloy, and not to any mechanical change produced by the mere fact of sudden cooling.

The comparative freedom of the molecules in a piece of iron was so enormous—the molecules turned and twisted with such facility—that when a wagon passed by in the street, the currents in his instrument kept moving like a magnetic needle, positive and negative, negative and positive alternately, so quickly that it was impossible to follow them. The molecules were so free that even a blow on the table shook them about and caused currents; but when he had them under torsion they were all fixed, and he was able to measure the effects. They had already seen that the magnetism in an iron wire was destroyed by shaking, and similarly in a bottle of filings. But now, instead of shaking, he would hold the bottle of filings steadily in a vertical position, and tap it hard on the table. Previously, when he had shaken it, he had shaken the molecules loose; but now they were not quite so loose, because they were lying on one another, and it would be seen that some magnetism remained, because they were not so free as they had been before. [Experiment shown.] That showed that the molecules of iron turned with far greater freedom than even the filings in that bottle.

They could thus perhaps imagine how, to a person working continually with the induction balance, the molecules, as they turned round, seemed to be no longer solid substances, but rather particles free to take up motion of every kind. In investigating those motions he had perceived a very great difference between iron and steel; and not only so, but between tempered steel and soft steel, and between soft steel and hard iron, and between hard iron and soft iron. Those differences he had noted, and reduced to a scale: he was now at work upon that question, and though he could not give exact figures then, he hoped to be able to do so on another occasion. However, he could give a slight idea of the difference in rigidity, as determined by his new instrument—a very superior instrument to that on the table, and one that had never yet been exhibited. Measuring the action in the case of cast-steel tempered, it had a value of 15° on his scale, while the value for soft iron was 3,776°, the degrees being the same throughout. Each sort of iron had a different number, so that by knowing the number they would know the constitution of the iron.

Mr. W. H. PREECE, F.R.S., said he had come to the meeting not so much to take part in the discussion as to obtain a knowledge of new facts from two such masters of their craft as Prof. Abel and Prof. Hughes; and he had not been disappointed. The facts which Prof. Hughes had shown that night were singularly instructive, and his paper formed an admirable sequel to that of Prof. Abel. The latter had brought before them very interesting facts with regard to the chemical constitution of steel; and Prof. Hughes, with the aid of the ear and the eye, had made them practically apprehend the movement of the infinitesimal molecules. They could almost see the dispersed carbon, in the form of an alloy, which made the difference between iron and steel, holding those iron molecules in an enchained condition, and so producing the magnetic difference between steel and iron which Prof. Hughes had illustrated.

For electrical purposes, in which he himself was deeply interested, it was a matter of very serious consequence to arrive at the reason why steel should behave so very differently from iron; in order thus to find some means by which to improve the quality of steel and iron. They wanted to render steel as strongly magnetic as possible; and the improvement in this respect within the last few years was very great. He could remember the time when they were perfectly satisfied if a magnet could hold up its own weight of iron; but in the Paris Exhibition of last year there was a magnet that would hold 76 times its own weight, and ordinary magnets of the present day, like those used in the Gower telephone, held up from 15 to 25 times their own weight. This great improvement in steel had been produced within the last four or five years. But in iron no improvement whatever had been made; there had rather been deterioration. In iron they wanted quite a different property, namely that, when it had become magnetised by a current, it should instantly, on breaking the current, lose its magnetism also. But from some cause or other—whether from the presence of carbon or other ingredients—it was almost impossible at the present day to obtain iron which was pure in this magnetic sense. He therefore wished to urge upon the Institution that there was room here for improvement. It was not perhaps a sphere where there was much money to be made, for

the simple reason that the quantity of iron used for telegraph purposes was very small; but telegraph engineers would be very much indebted to mechanical engineers if they would provide some means by which iron could be freed from the impurities it now possessed, and from retaining the particular coercitive force which Prof. Hughes had so strikingly brought before them.

Prof. Abel had referred to a process employed in France by M. Clemendot, for hardening steel by compression. That was a most interesting process, and, to his mind, fully confirmed the conclusions that Prof. Hughes had arrived at. M. Clemendot took an ingot of steel, raised it to a cherry-red temperature (a little over 1000° F.), and then submitted it to a pressure of about 15 tons per sq. in., under which pressure it was allowed to cool. It cooled very rapidly, and when cold it possessed all the properties that tempered steel possessed; and if it were magnetised, it retained its magnetism. It could also be forged to any shape, the only risk to be provided against being that it should not be burnt; and afterwards it could be magnetised and become a permanent magnet. It still retained its temper, and could be used for tools, arms, bayonets, &c. He had brought to the meeting a small magnet made by that process. It had never been tempered, as they understood the term "tempering," but it was merely hardened by cooling under compression. Although it was hardened in January 1882, and then magnetised, it was still a very powerful magnet, and appeared likely to retain its magnetism for a very long time. M. Clemendot's process had also a strengthening influence on steel. From the mean of 50 experiments it appeared that, while the non-compressed steel had a breaking strength of 60·5 kg. per sq. mm. (about 38 tons per sq. in.), when it was compressed the breaking strength increased to 76 kg. (48 tons); showing that the tenacity of the steel was considerably increased.

He did not think there were any papers on this subject in the English language; and the facts that he had brought before them were simply those that he had obtained from Mr. Gower. He had been particularly anxious to find out how the Gower magnets were made so strong, for he had had a hope that if he ascertained this, he might, by a roundabout process, get to know some mode

by which iron might be improved. He thought Prof. Hughes had perhaps led the way by showing that the difference between the one and the other was not a chemical but a molecular one; and if he would only devote his attention to producing iron of greater purity, the whole profession of telegraph engineers would be deeply indebted to him.

Sir FREDERICK J. BRAMWELL, F.R.S., wished to ask Mr. Preece in what sized masses the steel was dealt with in the process to which he had alluded; because, if it was only in small masses and had to be compressed between cold metal surfaces, one could quite understand that the result of hardening and tempering might be attained by the simple contact of the steel with those surfaces.

Mr. PREECE said that the process up to the present moment had only been applied to small masses, pressed between metallic surfaces, but in one of the letters which he had received from France an allusion was made to the probability of the system being applied to armour plates; and that would imply that the process was believed to be applicable to larger masses than those hitherto used.

Sir FREDERICK BRAMWELL said it appeared to him that up to the present time they had no evidence of anything more having been obtained than had often been obtained in steel manufacture previously; namely, the getting the result of the combined processes of hardening and tempering by the one process of the juxtaposition of heated steel with cold metallic surfaces.

Mr. ARTHUR PAGET believed Sir Frederick Bramwell was quite right in his remarks: in his own works he had for years been in the habit of hardening thin steel articles by the process of simply placing them in contact with cold iron plates, which abstracted heat without appreciable pressure. The hardening effect was complete and perfect: in fact the discs that Prof. Abel had been experimenting with had been hardened in that manner. Therefore, if M. Clemendot had experimented upon nothing thicker than the magnet shown, there

was no evidence that compression had any such effect as was claimed. He would undertake to say that, almost without any pressure at all, such a piece could be hardened certainly to one-third of its depth by the mere abstraction of heat caused by contact with cold iron plates.

Mr. W. SCHÖNHEYDER had understood Mr. Preece to say that, after the process of pressing steel between two surfaces, it could be *forged*, so long as it was not over-heated; and that the effect produced by compression did not disappear with forging. It could not therefore be simply the ordinary hardening process, because in that case the steel would return to its ordinary soft condition after having been heated. That appeared to be a proof that it had undergone some change by pressure, and not simply by cooling.

Sir FREDERICK BRAMWELL believed he was right in stating that the effect of oil-tempering on steel was such that it was possible subsequently to heat the steel up to a red heat, and allow it to cool slowly, and yet to retain nearly the whole of the temper that had been imparted to it by the oil process.

Prof. A. B. W. KENNEDY wished to ask Prof. Hughes whether he thought the results which he had given were in any way affected by the fact that a good deal of the material experimented on was drawn wire: in other words, by the state into which the surface of the material had been brought by drawing; and whether similar results would be obtained with larger specimens, which had not been artificially hardened in that way.

Prof. HUGHES, in reply to Prof. Kennedy, said the experiments shown that evening were on wires, but he had tried the same on bars ½ in. square, and even larger, and every bar showed the same result. By just touching the bar with the hand, so as to produce a slight torsion, he could hear, as it were, all the molecules turning round into their old places. It seemed perfectly impossible that he could with his fingers take a ½ in. bar and turn all the molecules round in that way; but it was so. He used wires simply because it was more

convenient: the size made no difference, except that the sounds were louder in proportion to the size. They increased as the diameter, not as the area; so that there was double the effect with double the diameter.

With regard to Mr. Preece's magnet, he could quite see, from his own experiments in magnetism, that if steel could be compressed sufficiently without tempering, it ought to retain its magnetism, because the molecules were pressed more closely together; they were thus made rigid, and anything that produced rigidity in molecules caused retention of magnetism. You might take a piece of iron, and hammer it so hard that it would retain magnetism far better than tempered steel.

In conclusion he might mention that all the results given that evening were in some measure due to the initiative of the Institution of Mechanical Engineers. They had formed a committee on the hardening and tempering of steel. He had at that time been working with the induction balance upon steel and upon magnetism; but there was no clear direction to guide him in his experiments. The Institution however kindly nominated him on their committee: he thus had a direction given to his researches, and the results were what they had seen, and what he hoped to give the Institution in a future paper.

The PRESIDENT said he was sure that every one present had, like himself, listened with great pleasure to the paper; and that they would accord Prof. Hughes a most hearty vote of thanks, both for the paper itself, and for the beautiful experiments which he had brought before them. He must express a hope that it would not be very long before Prof. Hughes favoured them with the results of the further experiments which he was conducting.

ON THE WORKING OF BLAST FURNACES, WITH SPECIAL REFERENCE TO THE ANALYSIS OF THE ESCAPING GASES.

BY MR. CHARLES COCHRANE, OF STOURBRIDGE, VICE-PRESIDENT.

The following paper is intended to deal with the working of the blast furnace considered by itself; and it is the object of the author to establish the fact that all economy in fuel consumed to make a ton of pig iron, with any particular class or size of furnace, is governed by three conditions:—

(1) The temperature of the air introduced into the furnace.

(2) The temperature of the escaping gases.

(3) The quantity of carbon which can be maintained in the condition of carbonic acid, after it has once been transformed to this degree of oxidation from the carbonic oxide produced in the hearth.

Generally speaking, and with any size of furnace, it may be said that the hotter the air the less the fuel required, the cooler the escaping gases the less the waste of fuel from this cause, and the higher the proportion of carbonic acid to carbonic oxide the higher the economy of fuel.

How the gross consumption of fuel per ton of pig is affected by the capacity (larger or smaller) of the blast furnace, and how such capacity has a direct influence on the temperature of the escaping gases, has been indicated by the writer in papers already read before this Institution (Proceedings, 1864, p. 163, and 1882, p. 279). It is now proposed, without reference to any particular capacities, to point out how and to what extent, in all or any furnaces, the consumption of fuel is affected by the three conditions named above; and what is the precise value, in fuel, of any given alteration in either

of these three factors. It will be assumed at the outset of the inquiry, that all the carbon of the fuel which reaches the hearth is transformed into carbonic oxide; and that, of the carbon so converted into carbonic oxide, a certain quantity is further converted into carbonic acid by the reduction of peroxide of iron (where calcined ironstone is used) into iron. This amount is arrived at by the chemical formula (old nomenclature), $Fe_2\,O_3 + 3\,CO = Fe_2 + 3\,CO_2$, where 18 parts by weight of the carbon are needed to reduce 56 of iron. It will be further assumed that the pig iron contains 3 per cent. of carbon and 3 per cent. of impurities, containing therefore 94 per cent. of pure iron. Thus 20 cwt. of pig iron contain:—

Pure Iron	18·80 cwt.
Fixed Carbon	0·60 „
Impurities	0·60 „
Total . .	20·00 cwt.

The quantity of carbon needed for the reduction of this 18·80 cwt. of iron from its state of peroxide will therefore be—
$\frac{18}{56} \times 18{\cdot}80 = 6{\cdot}043$ cwt.

This 6·043 cwt. of carbon, converted in this manner into carbonic acid, is the maximum quantity that can be so converted; and the amount of carbonic acid it produces is $\frac{11}{3} \times 6{\cdot}043 =$ 22·154 cwt. per ton of pig iron. Whilst it is impossible for this weight of carbonic acid (if produced from this source) to be exceeded in the blast furnace, it is possible for some of it to be reconverted into carbonic oxide by the absorption of an equivalent of carbon, according to the chemical formula, $CO_2 + C = 2\,CO$.

It does not concern the author to inquire at this moment what causes operate to produce this most objectionable change; but the greater the extent to which this reconversion takes place, the more carbon is absorbed from the fuel into the escaping gases, never to reach the hearth at all.

Such a transfer of carbon from the condition of carbonic acid to that of carbonic oxide obviously reduces the weight of the former, and increases the weight of the latter.

The value of the analysis of the escaping gases is that it affords the means of ascertaining the precise ratio of the two, and thence, after making all proper allowances and calculations, enables us to deduce the effective duty of the fuel employed in the furnace.

These calculations are somewhat laborious. They have been admirably worked out by M. L. Gruner in his work entitled "Études sur les Hauts-Fourneaux"; but it is not everyone who can afford the time to wade through the algebraical formulæ and the minute details into which that gentleman has entered.

It will be the author's aim to deal with the whole subject synthetically instead of analytically; and so endeavour to place it in a light in which it shall possess a more practical value for blast-furnace engineers.

I. Temperature of Blast.

Taking the simplest conditions first, it will be obvious that the quantity of heat carried into a blast furnace with the blast will depend simply on the actual weight and temperature of the blast itself. To illustrate this, the appended Table A, p. 124, has been constructed. In the column to the left hand appear weights of blast in cwts., ranging from 55 cwt. to 145. In the top line of the Table appear the successive temperatures, ranging from 50° Fahrenheit = 10° Centigrade, to 1600° Fahr. = 871° Cent.; whilst in the intersections of the respective horizontal and vertical lines will be found the weight in cwt. of carbon needed, when converted into carbonic oxide, to replace in the blast furnace the heat carried in by air of the corresponding weight and temperature.

Thus, if 90 cwt. of air per ton of pig iron be passing into the furnace at a temperature of 900° Fahr. = 482° Cent., this, as will be seen, is equivalent in heat to 4·19 cwt. of carbon burnt into carbonic oxide inside the blast furnace per ton of pig iron; or if at 1200° Fahr. = 649° Cent., this is equivalent to 5·65 cwt. of carbon burnt into carbonic oxide; or lastly, if at 1500° Fahr. = 816° Cent., this is equivalent to 7·09 cwt. of carbon burnt in the furnace to do the same work.

To calculate Table A, p. 124, it has been assumed that the specific heat of air compared with water is 0·239, and that the number of heat-units (Centigrade) developed by one unit (or cwt.) of carbon in its combustion into carbonic oxide is 2473. Thus, taking any one of the above as an example, say that of 90 cwt. of air at 816° Cent., it would represent $\frac{90 \times 816 \times 0 \cdot 239}{2473} = 7 \cdot 09$ cwt. of carbon. From this Table it will be seen how variations in temperature of blast affect the economy of fuel in the furnace; how for instance, in the cases above cited, supposing the weight of blast to be 90 cwt., the raising of its temperature from 1200° to 1500° represents a difference of $7 \cdot 09 - 5 \cdot 65 = 1 \cdot 44$ cwt.; and how again, on its rising from 1000° to 1500°, the economy is represented by the difference between 7·09 and 4·68 cwt. = 2·41 cwt. on the same quantity of blast. True it is that with such extra heat carried into the furnace, 90 cwt. of blast would no longer be required per ton of pig iron made; but whatever less weight of air would then be needed, as soon as the proper quantity is ascertained the economy can be at once seen from the Table.* One point, which cannot fail to strike anyone on a simple glance at either Table or diagram, is the gigantic stride which has been made in the economy of fuel in the blast furnace by the employment of heated blast. Thus the heating of 145 cwt. of blast from the temperature of the atmosphere to 1500° Fahr. = 816° Cent., would need the combustion of 11·43 cwt. of carbon burnt into carbonic oxide within the blast furnace; whereas this work is now done by what were wont to be called the waste gases passing from the tunnel head of the furnace. In addition, this extra carbon would necessitate the introduction of cold air to burn it, and would so create a larger volume of gases passing away at the tunnel head. No wonder then that to make cold-blast iron needed 40 cwt. or more of coke per ton of pig iron made, and required something like 10 tons' weight of blast per ton of pig iron to be introduced into the furnace. Any economy of fuel outside the

* The same figures have been projected in the form of a diagram, No. I., Plate 2, which it is hoped will explain itself after the description given above of the Table on which it is based.

furnace, which may be obtained by the use of waste gases, forms no part of our present study. So far as the working of the blast furnace itself is concerned, the escaping gases are the source of loss in economy.

II. TEMPERATURE OF ESCAPING GASES.

The second point proposed to be established is that economy of fuel consumed in a blast furnace is influenced by the temperature of the escaping gases, which must carry away a greater or less proportion of the heat actually generated in the blast furnace, according as their temperature is higher or lower.

It must be obvious that if, by way of illustration, we suppose 5 tons or 100 cwt. of gases to escape in one furnace at a temperature of 700° Fahr., and in another at a temperature of only 350° Fahr., the saving in the latter case will be found to be about one half the waste going on in the former; and so under any other conditions of weight of escaping gases, and temperature at which they escape. Thus the consumption of fuel in the furnace must have a direct relation to the joint conditions of weight and temperature of escaping gases. To arrive at a correct estimate of the possible economy under this head, it is necessary to know the specific heat of each of the escaping gases, viz., carbonic acid, carbonic oxide, nitrogen, and steam. As these differ slightly from each other, and the proportions are ever variable in the varying conditions of blast-furnace work, it is proposed in the following calculations to adopt the average specific heat given by M. L. Gruner in his "Études sur les Hauts-Fourneaux." He gives the following data:—

Specific Heat of CO	0·217
" " CO_2	0·226
" " N	0·244
" " HO (steam)	0·480.

From these he deduces a mean of 0·237 as the specific heat of the mixture. In the appended Table B, p. 125, this mean is adopted as the basis for calculation of the actual heat carried away by the gases escaping at the tunnel head of the furnace, according to the weight and temperature thereof. Here the vertical column on the left shows

the weight of gases, ranging from 75 cwt. to 200 cwt. per ton of pig produced, while the horizontal line at the top indicates the temperature of the escaping gases, ranging from 250° Fahr. = 121° Cent. to 1000° Fahr. = 538° Cent. At the intersections of the co-ordinate lines in this Table are given the amounts of carbon, burnt into carbonic oxide within the furnace itself, which are needed to heat the corresponding weight of gases in the vertical column to the corresponding temperatures indicated, from 121° Cent. upwards. This Table has also been projected into the form of a diagram, No. II., Plate 3, which it is hoped will sufficiently explain itself by the aid of these observations. To cite an example :—140 cwt. of gases heated to 700° Fahr. = 371° Cent. will carry away the equivalent of 4·98 cwt. of carbon, burnt into carbonic oxide; and will actually rob the furnace of this amount of effective heat. If that same weight of 140 cwt. of escaping gases can be cooled to 350° Fahr. = 177° Cent., the actual amount of carbon burnt into carbonic oxide in the furnace, to represent this waste of heat, will be only 2·37 cwt. Hence such a reduction in temperature of escaping gases (namely from 700° Fahr. = 371° Cent. to 350° Fahr. = 177° Cent.) would be accompanied by a saving of carbon, burnt into carbonic oxide, to the extent of the difference between 4·98 cwt. needed in the former case and 2·37 cwt. needed in the latter; or a saving of 2·61 cwt. of carbon on the weight of 140 cwt. of escaping gases. This comparison will be sufficient to point out the value of the Table.

The mode of calculation, to arrive at the heat carried away by the waste gases, is simply to multiply the weights in cwt. by their temperature in Centigrade degrees, and again by the specific heat, or 0·237, and finally to divide by 2473, being the number of units of heat developed by the combustion of 1 cwt. of carbon into carbonic oxide.

The further value of this Table will be evident on considering the conditions under which blast furnaces are worked. There are times when the furnace is allowed to go down. For want of materials to absorb the heat of the escaping gases, their temperature then rises abnormally—in some cases 300° or 400° Fahr., or even more.

If furnaces are driving fast, and the appliances for hoisting are inadequate, it may need two or three hours after a stoppage

at meal-times to restore the normal working of the furnace. Suppose now that 140 cwt. of gases are escaping per ton of iron produced, at any particular furnace, and that the normal temperature of the escaping gases, when the furnace is full, is 500° Fahr. = 260° Cent.; then the carbon burnt into carbonic oxide within the furnace to meet this demand would be 3·49 cwt. per ton of pig iron. But suppose, by one hour's neglect of charging the furnace, the temperature of the escaping gases rises to 700° Fahr. = 371° Cent., then the waste is going on at the rate of 4·98 cwt. of carbon per 140 cwt. of escaping gases, and the actual loss in the furnace per ton of iron in that case is 4·98 – 3·49, or 1·49 cwt. of carbon for each ton of iron made during the period this abnormal condition of things is allowed to last.

Another important deduction from this Table is the enormous influence which the escaping gases exercised in former years, when small furnaces and cold blast were employed in the manufacture of pig iron.

But perhaps the most important use to which this Table may be applied is the indication it gives in any particular furnace (where the normal condition of escaping gases has been ascertained) as to any irregularity which may have arisen in the furnace itself, by reason of scaffolds of any class or kind.

It is true that scaffolds on any segment of a furnace may be speedily detected by the circumstance of the materials charged into the furnace descending more quickly on the side opposite to that on which the scaffold exists, than on the other. But there are scaffolds, specially those of the annular form, or ring scaffolds, which are not so easily detected, but which are at once discovered by the judicious use of a pyrometer, to indicate the temperature of the escaping gases. In such cases the Table will point out the fact that the furnace has sustained a diminution in its working capacity; and will indicate the loss sustained by the combustion of extra carbon in the furnace, needed to make up for the increased temperature of the escaping gases. For more detailed information as to the extent of enlargement of a blast furnace, which is needed to accomplish a definite economy by reducing the temperature of the escaping gases, see Proceedings, 1869, pp. 25 and 45.

III. Maintenance of Carbon in the form of Carbonic Acid.

This, the third point with which we have to deal, is perhaps the most important of the three under consideration; at any rate it is the most subtle in its action, and has the most serious influence on the consumption of fuel in a blast furnace. Let it be remembered that 1 lb., 1 cwt., or 1 ton (any unit in fact) of carbon, if burnt into carbonic oxide, will develop 2473 corresponding units Cent. of heat; by which is meant that 1 lb., 1 cwt., or 1 ton of carbon, burnt into carbonic oxide, will heat 2473 lbs., cwts., or tons of water from 0 to 1° Cent., or 1 lb., 1 cwt., or 1 ton of water from 0° to 2473° Cent. (if such a temperature were attainable by water). Let it be further remembered that 1 lb., 1 cwt., or 1 ton of carbon burnt into carbonic acid will develop 8080 such units—that is, will heat 8080 lbs., cwts., or tons of water from 0° to 1° Cent., or 1 lb., 1 cwt., or 1 ton of water from 0° to 8080° Cent. It will then at once be seen how important it is, with regard to economy of fuel in a blast furnace, that we should ensure the combustion of every unit of carbon, if possible, into the more highly oxidised gas called carbonic acid; and furthermore, when once burnt into carbonic acid, that we should *never allow it to pass back again into the condition of carbonic oxide*, if such a step be preventible. The conversion of 1 lb. of carbon from carbonic acid into carbonic oxide can only be accomplished by the absorption of carbon, according to the formula, $CO_2 + C = 2\,CO$; but in the process the heat lost is measured not only by the loss of the carbon so absorbed to convert carbonic acid into carbonic oxide, which carbon never reaches the hearth to be burnt by the blast, but also by the great difference existing between the heat equivalent of the carbon, as burnt into carbonic oxide and carbonic acid respectively.* As already mentioned, 1 lb., 1 cwt., or 1 ton of carbon burnt into carbonic oxide develops only 2473 units of heat, but if burnt into carbonic acid develops 8080; in other words the carbon burnt in the latter case is practically worth $\frac{8080}{2473} = 3 \cdot 27$ times as much as the former. To make this point perfectly clear, we may say that it would require 3·27 lbs., cwts., or

* The reason of this second loss is of course that this quantity of heat is actually absorbed when the CO_2 returns to the condition of CO.

tons of carbon burnt into carbonic oxide, to do the work of 1 lb., 1 cwt., or 1 ton of carbon burnt into carbonic acid. Hence it will readily be seen how important it is that, if any carbon in a blast furnace is once converted into carbonic acid, it should remain in that condition.

Now in the blast furnace all the carbon *which reaches the hearth*, by contact with the incoming blast becomes converted into carbonic oxide; and the only reaction by which this carbonic oxide can be afterwards converted into carbonic acid is that which is undergone on its contact with the oxide of iron of the ore, and by which the reduction of that ore is accomplished.*

The direct effect of this reduction, as has been already indicated at p. 94, would be [if the ironstone were perfectly calcined, and all the iron therefore in a state of peroxide] a consumption of 6·043 cwt. of carbon per ton of pig iron; whilst the resulting weight of carbonic acid would be 22·154 cwt. per ton of pig iron.

Were it possible to maintain all this carbonic acid in the state of oxidation it has now reached, then, within any particular furnace, and so far as this chemical reaction is concerned, no further economy could be sought for. Unfortunately there are conditions which favour the reconversion of this carbonic acid into carbonic oxide; especially its contact with red-hot coke within the furnace. Hence it will now be our aim to calculate the effects of the absorption of successive increments of carbon, so as to produce the reconversion of carbonic acid into carbonic oxide; and finally to show how the absorption can be prevented in whole or in part. It is proposed to assume the absorption, first of ½ cwt. of carbon per ton of pig, then of 1 cwt., then of 1½ cwt., and so on up to 3 cwt.; and also to calculate at each step the altered relations of carbonic acid to carbonic oxide, and so by a synthetical process to arrive at the precise meaning of the analysis of blast-furnace gases, as given by the chemist.

For the sake of establishing a means of comparison, the standard

* The influence of hydrogen is here ignored, both for the sake of simplicity and because it is a trifling element in the main results.

of reference which has been adopted is that of a series of ideal furnaces, consuming respectively 10 cwt. to 34 cwt. of carbon per ton of pig iron produced, and rising by successive additions of 1 cwt. In all these ideal standards of reference it is assumed that the chemical action of the furnace is perfect; so that 6·043 cwt. of carbon per ton of pig actually becomes converted into carbonic acid, and remains as such. In a blast furnace there is a further amount of carbonic acid furnished by the limestone; but this, it is to be feared, is converted wholly, or almost wholly, into carbonic oxide, by contact with red-hot coke, and escapes at the tunnel head as such. Of this fact however the author for the present takes no cognizance, and assumes for the purpose of this ideal furnace that all carbonic acid in limestone will leave the tunnel head in the condition in which it is evolved. It is proposed in fact to deal with the following calculations as if the CO_2 produced by the reaction of CO on Fe_2O_3 were alone in question. The evolution of the carbonic acid from the limestone would thus form a positive addition to the carbonic acid formed by the reduction of peroxide of iron, and must be taken account of to enable a correct appreciation to be formed of the ratio of carbonic acid to carbonic oxide, as analysed in the escaping gases. It has been assumed that 12½ cwt. of limestone is used per ton of pig iron, and that this limestone is perfectly pure, yielding therefore $\frac{12 \cdot 5 \times 22}{50} = 5 \cdot 5$ cwt. of carbonic acid:* which, added to 22·154 cwt., yielded in the perfect reduction of the peroxide of iron of the ironstone, gives a total of 27·654 cwt. When dealing with the successive consumption of 10, 11, 12 &c. cwt. of carbon per ton of pig iron consumed in the *ideal* furnace, it will be seen from the appended Table C, p. 126, that the ratio of carbonic acid to carbonic oxide undergoes a steady reduction from 3·53 to 0·43. The Table has been calculated with reference to pure carbon, and not coke, in order to get rid of the correction for ash, moisture, and sulphur in the coke. It is easy for any one to adapt the Table to his own particular case, by the addition of the requisite amount to convert carbon into coke, or *vice versâ*, according

$$* \quad \frac{CO_2}{CaO,CO_2} = \frac{6 + 16}{(20 + 8) + (6 + 16)} = \frac{22}{50}$$

to the percentage of impurities contained in his coke. To complete our description of the ideal standard of reference, it is needed to point out that, for every successive increase of 1 cwt. of carbon consumed, a quantity of carbonic oxide must result from the carbon left over, beyond the 6·043 cwt. which by hypothesis is converted into carbonic acid, and also after allowing* 0·60 cwt. as being absorbed by the pig iron itself.

Thus, if 20 cwt. of carbon be the total consumed in the furnace, and if 6·043 cwt. be converted into carbonic acid, there will remain $20 - 6 \cdot 643 = 13 \cdot 357$ cwt. in the condition of carbonic oxide, and giving $13 \cdot 357 \times \frac{7^{\dagger}}{3} = 31 \cdot 17$ cwt. of that gas.

In this way has the standard of reference been calculated; and the results are presented in the *first* group of three columns, Table C appended, p. 126; in which no carbonic acid once formed (either by reaction of carbonic oxide on peroxide of iron, or by evolution from carbonate of lime) is supposed to undergo any change back to carbonic oxide.

For example:—In the case of 20 cwt. of carbon consumed in the ideal furnace, the quantity of carbonic acid is shown by the Table to be 27·654 cwt. per ton of pig iron, and that of carbonic oxide to be 31·17. The former divided by the latter gives the figure of 0·89, which appears in the Table as the ratio by weight of carbonic acid to carbonic oxide; in other words, for every single cwt. of carbonic oxide escaping at the tunnel head, there escapes in this case 0·89 cwt. of carbonic acid. The higher this figure, the better is the working of the furnace, so far as relates to the chemical reactions within the furnace itself.

Suppose now that from the cause indicated above, namely the contact of carbonic caid with red-hot fuel, ½ cwt. of carbon is absorbed in the upper regions of the furnace; then the second main column in the Table, itself consisting of three minor columns, shows in what

* The absorption of 0·60 cwt. of carbon per ton of pig iron is calculated on the basis of the deposit of 3 per cent. of carbon in the pig, as assumed by M. L. Gruner in his work "Études sur les Hauts-Fourneaux."

† $\frac{CO}{C} = \frac{(6+8)}{6} = \frac{7}{3}$

way and to what extent the relations between carbonic acid and carbonic oxide will be disturbed. The amount of the former will be reduced by $0 \cdot 50 \times \frac{11^*}{3} = 1 \cdot 83$ cwt., whilst that of the latter will be increased by 3·81 cwt., as arrived at in the following way. In consequence of the transfer of 0·50 cwt. of carbon from carbonic acid to carbonic oxide, and its consequent subtraction from the gross quantity existing in the former condition in the ideal furnace, there is necessarily a loss of heat, due to the fact that a unit of carbon burnt into carbonic acid develops 8080 units of heat, whilst a like unit burnt into carbonic oxide only develops 2473 units, and that a quantity of heat equal to the difference between these numbers is lost when a cwt. of carbon is re-converted from CO_2 to CO. To make up therefore for this failure of ½ cwt. of carbon, not burnt into carbonic acid, we shall need $\frac{8080 \times 0 \cdot 50}{2473} = 1 \cdot 63$ cwt. of carbon burnt into carbonic oxide, towards which there exists the ½ cwt. now transferred. This leaves a positive addition of 1·13 cwt. of carbon per ton of pig iron needing to be made to the fuel of the furnace, in order to compensate for the deficiency referred to. The result, direct and indirect, of the transfer of ½ cwt. from the higher state of oxidation to the lower will be to produce $1 \cdot 63 \times \frac{7}{3} = 3 \cdot 81$ cwt. of carbonic oxide to be added to the amount of carbonic oxide, as before stated, which exists in the ideal perfectly-working furnace. For the sake of illustration, we will again quote the case of 20 cwt. of carbon per ton of pig iron consumed in the ideal working. From the 27·654 cwt. of carbonic acid produced in that case, there have been removed 1·83 cwt. by the transfer of ½ cwt. of carbon, leaving 25·824 cwt. of carbonic acid; whilst there have been added 3·81 cwt. of carbonic oxide to the 31·17 cwt. already existing, thus making a total of 34·98 cwt. The ratio of carbonic acid to carbonic oxide is now therefore that of 25·824 to 34·98, or 0·74. To put the case in other words, the absorption of ½ cwt. of carbon by the carbonic acid has necessitated such an extra provision of fuel in the

$$* \frac{CO_2}{C} = \frac{(6 + 16)}{6} = \frac{11}{3}$$

blast furnace, as to require 1 cwt. of carbon to be burnt into carbonic oxide for only 0·74 cwt. burnt into carbonic acid; whilst in the ideal furnace the proportion of the latter was 0·89.

In like manner have the successive columns been calculated, showing the changes of ratio due to the successive transfer of 1 cwt., 1½ cwt., 2 cwt., 2½ cwt., and 3 cwt. of carbon; and the diagram No. III., Plate 4, has similarly been constructed, illustrating by a series of curves the results thus arithmetically arrived at.

In this diagram the figures arranged horizontally show ratios of carbonic acid to carbonic oxide, from 0·15 to 2·55; whilst those arranged vertically show consumptions of carbon per ton of pig iron, from 10 cwt. to 40 cwt. The Table and diagram will deserve some consideration; for it will be seen that from the mere ascertained ratio of carbonic acid to carbonic oxide, as given by the analysis of the gases escaping from the tunnel head of a blast furnace, it is utterly impossible to determine with what amount of fuel the furnace is working.

A glance at either the Table or diagram will show the impossibility of arriving at any such determination from mere analysis of the gases. For instance, suppose that an analysis of the gases gave a ratio of 0·60 between the carbonic acid and carbonic oxide. What do we find from the Table? This might result either from the perfect working (chemically speaking) of a small ideal furnace, consuming a little over 26 cwt. of carbon per ton of pig iron; or from the ill working of another furnace, in which by imperfections of arrangements ½ cwt. of carbon had become transferred from carbonic acid to carbonic oxide, but where the consumption of carbon per ton of pig had fallen to about 24·50 cwt.

In like manner the existence of the same ratio 0·60 may mean a totally different state of things from either of the above: for if 1 cwt. of carbon have changed its state from superior to lower oxidation, *i.e.* from carbonic acid to carbonic oxide, then it appears from the diagram that such a ratio may refer to a furnace in which the actual consumption of carbon is 22·75 cwt. per ton of pig iron, and so far will indicate a better condition of furnace-working than in the ideal furnace with which we started. For the latter, with a ratio of 0·60, consumed by hypothesis over 26 cwt. of carbon; whilst the imperfect

furnace, having suffered a transfer of 1 cwt. of carbon from the condition of perfect to that of imperfect combustion, may be working, by reason of its advantages in other respects, at the much lower consumption of about 22·75 cwt. of carbon.

In like manner, should 1½ cwt. of carbon have been transferred, we still find by a reference to the diagram that such a ratio of carbonic acid to carbonic oxide as 0·60 may yet hold in a furnace of superior appliances, in which the consumption of carbon per ton of pig iron is only 20·9 cwt.

It will thus be seen how impossible it is, from a mere chemical analysis of the gases emerging from the tunnel head of a blast furnace, to draw any reliable conclusion as to the working of the furnace itself. What then is the value of such analyses? Taken in conjunction with the consumption of carbon per ton of pig iron, and other collateral circumstances, analyses are invaluable; but by themselves they are misleading. Hence, in order to form a correct appreciation of the value of the analysis of the gases, it will next be necessary to make an approximate estimate of the quantity of air admitted to the blast furnace and of the gases discharged therefrom, under the same successive conditions as to carbon burnt into carbonic acid in the ideal furnace, and its subsequent transfer to the condition of carbonic oxide by contact with red-hot coke. It matters not now, for the purpose of our calculations, whether it be the carbonic acid of limestone or the carbonic acid produced by the reaction between the oxide of iron and the carbonic oxide of the furnace, which undergoes the change referred to; but on the amount of such transfer of carbon must depend the quantity of carbon which reaches the hearth, and needs air for its combustion, as well as the total amount of gases escaping at the throat of the furnace.

We commence with the ideal work of a perfect furnace—that is a furnace of whatever capacity, and working under whatever conditions of temperature in the blast or of escaping gases, but with the supposed condition that no carbonic acid becomes reconverted into carbonic oxide. Table D, p. 127, has been constructed to show the weight of air in cwt. required to consume that portion of carbon which enters the furnace, and also reaches the tuyeres. In the case of the ideal furnace, the weight of carbon which reaches the tuyeres

to be consumed in the current of blast is less than that which enters the furnace, by the amount of carbon absorbed to convert pure iron into the carbide or carburet which forms the cast iron of commerce. This amount is taken in these calculations to be 0·60 cwt. per ton of pig iron. The Table further shows the weight of gases escaping from the tunnel head, under such supposed perfection of working.

In this Table it will be seen that the carbonic acid in the escaping gases is simply the amount due to a perfect reduction of all the peroxide of iron by carbonic oxide, plus that supplied by the 12½ cwt. of carbonate of lime; whilst the carbonic oxide is taken as in Table C, the construction of which has been already explained. The oxygen needed to be supplied by the blast is taken at $\frac{4}{3}$ the weight of the carbon to be burned to carbonic oxide (according to the chemical equivalents C = 6, O = 8), whilst the nitrogen is taken at $\frac{77}{23} = 3 \cdot 33$ times the weight of oxygen. No account is taken of moisture in the air, as being a refinement of calculation outside our present aim.

The next Table E, p. 128, shows the air passing into the furnace, and gases escaping therefrom, based upon the transfer of ½ cwt. of carbon from the state of carbonic acid to that of carbonic oxide. The effect of this transfer having been already explained, it is only necessary to present the Table as showing the changes in the fuel needed, in the air to be admitted, and in the gases produced, which are due to the transfer of ½ cwt. of carbon from the state of carbonic acid to that of carbonic oxide. Similarly, if we suppose a transfer of 1 cwt. of carbon from the carbonic acid found in the assumed perfect or ideal disposal of the carbon within the furnace, Table F, p. 129, shows the resulting changes in the air and escaping gases; and in like manner Tables G, H, I, J, pp. 130–133, show the changes in the fuel needed, in the air to be admitted, and in the gases produced, in furnaces in which have been effected transfers of 1½, 2, 2½, and 3 cwt. of carbon respectively from the condition of carbonic acid to that of carbonic oxide: the effect being due to the absorption of carbon in a red-hot state by carbonic acid coming in contact with it.

The whole of the above Tables, of weight of air introduced and weight of escaping gases, may be illustrated in the form of a diagram, No. IV., Plate 5, in which the vertical lines represent carbon consumed,

from 10 cwt. to 40 cwt., and the horizontal lines represent cwt. of air introduced or of gas escaping. The two series of diagonal lines indicate, by the points of intersection of co-ordinates through which they pass, the relation between carbon consumed and weight of air needed in the air series, and between carbon consumed and weight of gas produced in the gas series.

The result of what has gone before is to enable us to establish a standard of reference for the working of any furnace, under certain conditions of materials, namely, in the case about to be chosen, Cleveland ironstone containing about 41 to 42 per cent. of iron in the calcined state, and producing about 30 cwt. of slag per ton of pig iron; and thus to show how far the actual working of a furnace, of whatever capacity, differs, in cwt. of carbon per ton of pig iron produced, from a furnace working under ideal or perfect conditions. To quote a particular case. In November 1881, the following analysis was made of gases escaping from No. 3 furnace (20,454 cub. ft. capacity) at Ormesby Iron Works, Middlesbrough:—

$$\begin{aligned} CO_2 &= 13 \cdot 42 \text{ by weight.} \\ CO &= 31 \cdot 66 \quad \text{,,} \\ H &= 0 \cdot 12 \quad \text{,,} \\ N &= 54 \cdot 80 \quad \text{,,} \\ & \overline{100 \cdot 00} \end{aligned}$$

$$\text{The ratio } \frac{CO_2}{CO} = \frac{13 \cdot 42}{31 \cdot 66} = 0 \cdot 424$$

The temperature of blast was . .	700° C.
That of the gases was . . .	340° C.
The carbon in coke was . . .	21·98 cwt.
The carbon in limestone was taken at	1·50 cwt.

By reference to the Table C or to Diagram III., Plate 4, showing ratio $\frac{CO_2}{CO}$ and carbon consumption, we find that the number 0·424 as the ratio of CO_2 to CO corresponds to several different conditions, as follows:—

(1) To the condition of an ideal furnace, consuming 34 cwt. of carbon per ton of pig;

(2) Of a furnace in which ½ cwt. of carbon has become transferred from the condition of CO_2 to CO, with a modified consumption of 32 cwt. of carbon per ton of pig;

(3) Of a furnace in which 1 cwt. of carbon has been transferred from condition of CO_2 to CO, with a further modified consumption of 29·75 cwt. of carbon per ton of pig;

(4) Of a furnace in which 1½ cwt. of carbon has been transferred from the condition of CO_2 to CO, with the modified consumption of 27·5 cwt. of carbon per ton of pig;

(5) Of a furnace in which 2 cwt. of carbon has been transferred, and the corresponding consumption is 25·25 cwt. of carbon per ton of pig;

(6) Of a furnace in which 2½ cwt. of carbon has been transferred, and the corresponding consumption is about 23 cwt. of carbon per ton of pig.

Obviously it would be impossible by the mere analysis of the gases to ascertain to which of these cases the analysis applied. But let it be known that at the same time that the analysis gave the ratio of CO_2 to CO $= 0·424$, the consumption of carbon on the ton of pig iron was 21·98 cwt.; and then there is at once the means of assigning to these combined conditions an approximate position in the Table C, and a very exact position in the diagram No. III. In the Table C the nearest figures are those of 0·45 for ratio, and 21·67 for carbon consumption. In other words our conditions of 0·424 ratio and 21·98 cwt. indicate a furnace working with 2½ cwt. or thereabouts of carbon transferred from CO_2 to CO, whilst the ideal furnace should only need 16 cwt. of carbon (the corresponding figure on the same line), had no such transfer taken place. The diagram No. III. shows the transfer to have been slightly more than 2½ cwt., but this figure is sufficiently exact for our purpose. The loss therefore is no less than $21·98 - 16·00 = 5·98$ cwt. of carbon, when compared with the perfect work of which such a furnace should be capable, if all the carbonic acid once formed could be maintained in that condition, and not allowed by surrounding circumstances to become re-converted into carbonic oxide.

To quote another case: in November 1881, the following analysis

was made of gases escaping from No. 2 furnace (35,013 cub. ft. capacity) at Ormesby Iron Works, Middlesbrough:—

$$
\begin{aligned}
CO_2 &= 18 \cdot 36 \text{ by weight.} \\
CO &= 26 \cdot 66 \\
H &= 0 \cdot 07 \\
N &= 54 \cdot 91 \\
\hline
& 100 \cdot 00
\end{aligned}
$$

The ratio $\frac{CO_2}{CO} = \frac{18 \cdot 36}{26 \cdot 66} = 0 \cdot 688$.

The carbon in coke was 17·96 cwt.

The carbon in limestone was nearly 1·50 cwt.

On reference to Table C, p.126, of ratios and carbon consumption, it may be noted in passing that the mere ratio $\frac{CO_2}{CO} = 0 \cdot 688$ (or say 0·69) might point (taken by itself) to an ideal furnace consuming a little under 24 cwt. of carbon, or to successive imperfect furnaces consuming a little over 22·13 cwt., or 20·26 cwt., per ton of pig; but when, in conjunction with the ratio $\frac{CO_2}{CO} = 0 \cdot 69$, the actual consumption of carbon consumed per ton of pig iron is known, as in this case, to be 17·96 cwt., we have thus the means of assigning to the conditions named a position in the Table, or on the diagram III.; and we find that somewhere about $1\frac{3}{4}$ cwt. of carbon has been transferred from its previous condition of carbonic acid into the lower state of oxidation. In the Table, the nearest approximation to the joint figures of ratio and carbon consumption is on the line of ideal consumption of 14 cwt. of carbon per ton of iron; and the meaning must simply be that with 14 cwt. of carbon per ton of iron, the whole work done within this blast furnace should have been accomplished. Why then has it needed 17·96 cwt. of carbon? Simply because about $1\frac{3}{4}$ cwt. of carbon has been removed from the state of CO_2 to CO, and has necessitated the addition to the ideal quantity of no less than 3·96 cwt. Let us test this: $1\frac{3}{4}$ cwt. of carbon as CO_2 develops $1 \cdot 75 \times 8080$ units of heat. But if it be turned into CO, it needs $\frac{8080 \times 1 \cdot 75}{2473} = \frac{14140}{2473} = 5 \cdot 71$ cwt. of carbon

burnt into carbonic oxide to replace the heat thus lost; towards this 1·75 cwt. already exists, necessitating the positive addition of 3·96 cwt. of carbon to compensate for the deficiency.

Attention may here be drawn to the circumstance that in both the cases above quoted (viz. No. 3 furnace with its ratio $\frac{CO_2}{CO} = 0 \cdot 424$ and consumption of 21·98 cwt. of carbon, indicating a transfer of $2\frac{1}{2}$ cwt. of carbon from its previous condition of CO_2 to that of CO; as well as No. 2 furnace with its ratio $CO_2 = 0 \cdot 688$, and consumption of 17·96 cwt. of carbon, indicating a transfer of $1\frac{3}{4}$ cwt. of carbon from its previous condition of CO_2 to that of CO), the quantities transferred exceed what could be due to the amount of 1·50 cwt. of carbon contained in the carbonate of lime. In the former case the excess is 1 cwt., and in the latter $\frac{1}{4}$ cwt. The question naturally arises—How does this happen? The answer will probably be found in the fact that all the 1·50 cwt. of carbon in the limestone employed as flux has been transformed from its previous condition of carbonic acid into carbonic oxide; and that, in addition thereto, 1 cwt. in the first case and $\frac{1}{4}$ cwt. in the second, of the carbon in the carbonic acid formed by the reduction of the peroxide of iron, has passed into the lower condition. The following causes operate to produce these results.

I. A red-hot temperature is needed to expel carbonic acid from limestone. But the coke, being red-hot also, must give up an equal weight of carbon to the carbonic acid evolved in its presence, and so the 1·50 cwt. of carbon is lost for all useful purposes in the hearth.

II. The largest pieces of ironstone do not get decomposed to the core until they also have reached a red-hot region, when the nascent carbonic acid (the result of the reaction between the carbonic oxide generated in the hearth and the oxide of iron) reacts upon the carbon of the coke, and absorbs, as in the cases quoted, an excess of carbon above the $1\frac{1}{2}$ cwt. previously referred to as due to the limestone. In the first case this extra loss was 1 cwt. and in the second case $\frac{1}{4}$ cwt., making the total losses respectively $2\frac{1}{2}$ cwt. and $1\frac{3}{4}$ cwt.

Under the operation of both the above causes—the necessity of a red-hot temperature to expel carbonic acid from limestone, and the descent of large pieces of ironstone into the red-hot region of coke—

the effect is just the same in destroying heat already generated in the furnace, as if carbonic acid were turned on from a tap (to the amount produced from $2\frac{1}{2}$ cwt. and $1\frac{3}{4}$ cwt. of carbon respectively) and made to pass over red-hot coke. In the first case the actual loss of heat would amount to $\frac{8080 - 2473}{2473} \times 2\frac{1}{2} = 5\cdot67$ cwt. of carbon burnt into carbonic oxide at the tuyeres; this being made up by $3\cdot40$ cwt. on account of $1\cdot50$ cwt. carbon in limestone, and $2\cdot27$ cwt. on account of $1\cdot00$ cwt. carbon transferred from the carbonic acid due to reduction of ore. In the second case the actual loss of heat would be equivalent to $3\cdot97$ cwt., namely $3\cdot40$ on account of limestone, and $0\cdot57$ on account of transfer of $0\cdot25$ cwt. from carbonic acid of reduction.

If the above reasoning and calculations be correct, there are two means of improving the present working of blast furnaces.

Obviously, if the limestone be calcined before entering the furnace, no carbonic acid will be evolved in the region of red-hot coke, and hence no absorption of carbon from this cause can take place. Again, to prevent the large pieces of ironstone from descending into red-hot regions before being perfectly reduced, they may be broken down to a size which will permit their reduction to take place in regions above those where nascent carbonic acid can do harm; or furnaces may be still further enlarged, and pressure of blast increased, to enable the large pieces of ironstone, although unbroken, to be reduced to the core before entering the region of red-hot coke.

We may take a third case, that of the working at the large furnaces at Ormesby Iron Works in May 1882, when the consumption of coke at the two furnaces fell as low as $18\cdot34$ and $18\cdot45$ cwt. respectively, say $18\cdot40$ cwt. average; whilst the ash, moisture, and sulphur therein was $9\cdot79$ per cent. We thus arrive at a condition in which the actual carbon consumed was $18\cdot40 \times \left(1 - \frac{9\cdot79}{100}\right) = 16\cdot60$ cwt. of carbon.

It is unfortunate that no analyses of the gases were made during that month; but it will be fair to assume that the economy arose from a less quantity of carbon being transferred from the condition of carbonic acid to that of carbonic oxide, than was the case when

17·96 cwt. of carbon were consumed, with a ratio $\frac{CO_2}{CO} = 0·69$, in November 1881.

If such be the case, it can at once be shown that the economy of 1·36 cwt. will have arisen from the maintenance, in the condition of carbonic acid once established, of* 0·60 cwt. of carbon: thus leaving a quantity of 1·75 − 0·60 or 1·15 cwt. of carbon, transferred to the condition of carbonic oxide. The ratio of carbonic acid to carbonic oxide will in this case be found as follows:—

CO corresponding to 1·36 cwt. carbon saved in May 1882, over November 1881 $= \frac{7}{3} \times 1·36 =$.	3·17 cwt.
Add CO from 0·60 cwt. C $= \frac{7}{3} \times 0·60 =$.	1·40 "
Total loss in CO	4·57 "

Gain in CO_2 corresponding to 0·60 cwt. C $= \frac{0·60 \times 11}{3} = 2·20$ cwt.

The ratio $\frac{CO_2}{CO}$, when 17·96 cwt. of carbon were consumed in November 1881, on the $1\frac{3}{4}$ cwt. curve of transfer referred to an ideal consumption of 14 cwt., would be $\frac{21·237}{30·489} = 0·696$. Hence the ratio $\frac{CO_2}{CO}$, when only 1·15 cwt. of carbon was transferred in May 1882, would be—

$$\frac{21·237 + 2·20}{30·489 - 4·57} = \frac{23·437}{25·919} = 0·90.$$

This corresponds, as it should do, to a curve on diagram III., Plate 4, of about 1·15 cwt. transfer, and to a consumption of 16·60 cwt. of carbon per ton of iron; and exhibits the case of such a low conversion of carbonic acid into carbonic oxide as to be represented, in a furnace of ideal working, by a consumption of 14 cwt. of carbon only per ton of iron used.

The result of the above is that, under existing conditions, it appears possible, in a furnace of 35,000 cub. ft. capacity, to

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* $\frac{x \times 8080}{2473} - x = 1·36$, $5607x = 3363·28$, $x = 0·60$

approximate within $1\frac{1}{4}$ cwt. of transfer to the ideal working of the blast furnace. On the other hand, the assumed amount of carbon existing in the limestone employed as flux is as much as $1\frac{1}{2}$ cwt., showing there has been complete reduction of the peroxide of iron without subsequent change of carbonic acid produced thereby, and also that a part even of the carbonic acid in the limestone is still retained in that condition.

Ratio of Carbonic Acid to Carbonic Oxide as affected by Carbonate of Lime.

This seems to be the proper stage of our inquiry to point out the effect of the presence of more or less carbonate of lime on the ratio of carbonic acid to carbonic oxide. We assume, as we are now compelled to do, that the liberation of carbonic acid from carbonate of lime takes place in a region of red-hot coke, where the whole or greater portion of the nascent carbonic acid immediately becomes converted into carbonic oxide.

It has been assumed up to the present that $12\frac{1}{2}$ cwt. of limestone have been consumed per ton of pig iron produced in every case—whether in the ideal furnace consuming from 10 to 35 cwt. of carbon, or where there is a departure from the adopted standard of reference by successive *transfers* of carbon ($\frac{1}{2}$ cwt., 1 cwt., &c.) from the condition of carbonic acid once formed to that of carbonic oxide. Such an assumption was needed to simplify the calculations, and to make the results strictly comparable. As a matter of fact however, every reduction in the consumption of fuel, consequent on the employment of higher temperature of blast and of furnaces of enlarged capacity, has been accompanied by a sensible reduction in the quantity of flux required. The direct effect in such cases is to reduce the quantity of carbonic acid liberated by the limestone in the region of the red-hot coke.

To take a hypothetical case, so far as limestone is concerned, let us see what would be the effect in a furnace of using only 10 cwt. of limestone instead of $12\frac{1}{2}$. In the former case the carbon would be $\frac{6}{50} \times 10 = 1 \cdot 20$ cwt. per ton of pig iron; whilst in the latter it

would be $\frac{6}{50} \times 12\frac{1}{2} = 1 \cdot 50$ cwt. Thus the difference would be 0·30 cwt. of carbon per ton of pig iron in favour of the lesser consumption of flux. This carbon, in the case of the larger consumption of flux, would necessarily absorb its own weight = 0·30 cwt., so as to become converted into carbonic oxide. But the mischief would not end there: for the heat lost in the actual process of absorption, measured in carbon burnt into carbonic oxide at the tuyeres, would be $\frac{8080 - 2473}{2473} \times 0 \cdot 30 = 0 \cdot 68$ cwt.

Influence on Consumption of Carbon of perfectly calcined Ironstone descending into the red-hot Coke region.

As far as possible, all ironstone should be reduced in a coke region where the coke is not red hot; because, as has been well pointed out by Mr. I. L. Bell in his researches on the blast furnace, the reduction of ore, whether calcined or raw, in the Cleveland district (and the same may be said of other districts), can take place at a temperature below red heat. Hence, in furnaces of proper construction, it can be accomplished without the carbonic acid due to the ore coming into contact with red-hot coke at all. In actual practice, with furnaces of inferior construction, and where no attention is paid to the size of the pieces of ironstone introduced into them, large pieces do find their way down into the red-hot coke region, before the carbonic oxide has effected the reduction of the mass to the core.

The inevitable result of this is the disengagement of a quantity of carbonic acid in the red-hot coke region, which must do exactly the like mischief to that described above, in the case where limestone is calcined in that same region.

Thus, should 20 per cent. of the ironstone be in such large pieces that only one half of it is decomposed before it reaches the red-hot coke region, then 10 per cent. of the whole consumption of ironstone per ton of pig iron would be subjected to the injurious process referred to. Taken per ton of pig iron, we have seen, page 94, that 18·80 cwt. of chemically pure iron exists in the state of peroxide in perfectly calcined stone; and that the quantity of carbon needed for its

reduction from peroxide is 6·043 cwt. Now in the above hypothetical case, supposing all the 10 per cent. of ironstone referred to were to give off the carbonic acid of reduction in the region of red-hot coke, the risk would be that $\frac{1}{10}$th of 6·043 cwt. carbon would be transferred from the condition of carbonic acid to that of carbonic oxide; thus producing a positive loss of 0·604 cwt. of carbon, which would never reach the hearth at all. The loss in heat, in addition to this, would be equivalent to $\frac{8080 - 2473}{2743} \times 0{\cdot}604 = 1{\cdot}36$ cwt. carbon required to be burnt at the tuyeres, in order to compensate for the above unburning of 0·604 cwt. carbon from the condition of carbonic acid back to carbonic oxide.

Influence of imperfectly calcined Ironstone on the consumption of Carbon.

Of still greater importance is the effect of imperfectly calcined stone, where it is introduced into the blast furnace in large lumps, and where these are allowed to reach the region of red-hot coke before disengaging all their gaseous contents. In practice, it is the large lumps of raw ironstone which generally escape calcination to the core, and which are therefore calculated to do the greater mischief about to be pointed out. In the case of the reaction between peroxide of iron and carbonic oxide, it can be readily shown from the formula of reaction* that for every 56 parts by weight of iron there are formed 66 of carbonic acid. But if the reaction takes place between carbonate of iron ($Fe\,O, CO_2$) and carbonic oxide, the formula of reaction will show† that for every 56 parts by weight of iron there are formed 88 of carbonic acid; or just one-third more than if the ironstone had been perfectly calcined.

Supposing then that 20 per cent. of the ironstone is both imperfectly calcined, and also introduced in large lumps, and that in consequence only the exterior half of perfectly calcined stone is

* $Fe_2O_3 + 3\,CO = Fe_2 + 3\,CO_2$
$56 + 24 + 3\,(6 + 8) = 56 + 66.$

† $2\,(FeO,CO_2) + 2\,CO = Fe_2 + 4\,CO_2$
$2\,(28 + 8 + 22) + 2\,(6 + 8) = 56 + 88.$

reduced before the red-hot coke region is reached; then the result would be to liberate not merely 0·60 cwt. of the carbon in the state of carbonic oxide amidst the red-hot coke, but also a further quantity of $\frac{1}{3}$ (0·60) = 0·20 cwt., making 0·80 cwt. in all. Should all this be converted into carbonic oxide by the absorption of red-hot carbon, the fuel requisite to replace it in the hearth would be $\frac{8080-2473}{2473} \times 0 \cdot 80 = 1 \cdot 81$ cwt.

In all the above cases it will be readily understood how the relations of carbonic acid to carbonic oxide will have been materially disturbed, so as to make a bare analysis unreliable as to telling the whole tale of the evil.

Disposal of Heat in the Furnace.

It is now proposed to point out, from our knowledge of the ratio of carbonic acid to carbonic oxide in the escaping gases, and of the consumption of carbon per ton of pig iron, in what way the combined sources of heat in the blast furnace are disposed of. To this end it will be requisite to premise that the melting of 1 cwt. slag requires 550 calories or Centigrade heat-units, as stated by Mr. I. L. Bell, and adopted by M. Gruner. Hence, assuming, as is approximately true in the Cleveland district, that 30 cwt. of slag are melted per ton of pig iron made, the quantity of carbon burnt into carbonic oxide to effect its fusion would be $\frac{30 \times 550}{2473} = 6 \cdot 67$ cwt. In like manner the decomposition of $12\frac{1}{2}$ cwt. of carbonate of lime requires $\frac{12 \cdot 5 \times 373 \cdot 5}{2473} = 1 \cdot 88$ cwt. Lastly, the loss by evaporation of water from the coke, by decomposition of water in the blast, and the losses by radiation, evection, &c., will amount together to about 3·44 cwt. more.

Our first example shall be that of No. 2 furnace at Ormesby Iron Works, Middlesbrough-on-Tees, having 35,013 cub. ft. capacity, of which the results are given in Table K, p. 134. An analysis of the gases was made in November 1881, with the following results by weight:—

CO_2	CO	H	N	Total
18·36	26·66	0·07	54·91	100·00.

Hence $\frac{CO_2}{CO} = \frac{18 \cdot 36}{26 \cdot 66} = 0 \cdot 688.$

The particulars of working were as follows:—

Temperature of blast	1256° F. = 680° C.
Temperature of escaping gases . . .	375° F. = 179° C.
Coke consumed per ton of pig iron . .	19·81 cwts.
Ash (8·91 per cent.)	1·76 „
Carbon consumed per ton of pig iron . .	18·05 „
Limestone consumed per ton of pig iron (actual)	12·49 „
Carbon contained in the above limestone (if pure CaO,CO_2)	1·50 „

Referring to Table C and Diagram III., Plate 4, it will be found that a furnace showing 0·688 as the ratio of carbonic acid to carbonic oxide, and consuming 18·05 cwt. of carbon per ton of pig iron, must be referred to a curve intermediate between that of 1½ cwt. and that of 2 cwt. transfer of carbon; and on further taking the precise point of intersection of the above co-ordinates of ratio and carbon consumption, the curve will be found to be one of 1·75 cwt. transfer. Now the ideal furnace, from which this is a departure, should work with 14 cwt. of carbon per ton of pig iron: so that there would have been a further saving of 3·46 cwt. of carbon, if only the 1·75 cwt. above referred to had not been transferred from carbonic acid to carbonic oxide. A series of dotted lines will be observed on Diagram III., intersecting the main curves already described. By following these from any point in question, until they intersect the ideal curve, the consumption in perfect working, corresponding to the conditions of any given furnace, may be ascertained, and by subtraction the extent of departure from perfect work is at once determined.

A reference to Diagram IV., Plate 5, will enable us to discover that the weight of air in cwts. passing into No. 2 furnace in November 1881, per ton of pig iron made, was 91 cwt.; whilst the weight of escaping gases was 122 cwt. The total heat carried in by 91 cwt. of air at the observed temperature of 680° Cent. is represented, according to Table A, by 6 cwt. of carbon burnt into CO. Hence the total carbon to account for is 6·00 + 18·05 = 24·05 cwt. The 122 cwt. of waste gases carry away, according to Table B, heat represented by 2·11 cwt. of carbon burnt into CO. Thus we have the following disposal of

the heat introduced into the furnace, measured in cwt. of carbon per ton of pig:—

	cwt.
Heat carried away by waste gases	2·11
Deposited carbon (3 per cent. of the pig iron)	0·60
Carbon absorbed under the law of transfer by conversion of CO_2 into CO	1·75
Extra carbon needed to meet the loss of heat due to such transfer (according to the formula $\frac{8080 \times a}{2473} - a$, where a is the weight of carbon transferred) . .	3·46
Carbon needed for decomposing limestone	1·81
Carbon remaining as Carbonic acid (6·043 − 1·75). .	4·29
Carbon burnt into carbonic oxide at the tuyeres, needed to melt 30 cwt. of slag	6·67
Carbon for sundries, including radiation, evaporation of water from the coke, decomposition of water in the blast, evection by tuyere water, &c., &c.	3·44
Carbon for melting iron is included in the Carbon needed for reducing purposes, the heat developed in the process of reduction being sufficient for fusion, according to M. L. Gruner	0·00
Total . .	24·13
Error in excess . .	0·08
	24·05

In like manner Table K, p. 134, shows the results of a comparison between the total carbon to account for, and the way in which it is disposed of, in each of the following cases:—

No. 3 furnace, 20,454 cubic ft. capacity, working in November 1881, with a consumption of 24·12 cwt. of coke per ton of pig.

No. 4 furnace, 20,454 cubic feet capacity, working in the same month with a consumption of 24·98 cwt. of coke per ton of pig.

Nos. 1 & 2 furnaces, average capacity 34,206 cubic ft., working in May 1882, with the very low consumption of 18·40 cwt. of coke per ton of pig.

Nos. 3 & 4 furnaces, each of 20,454 cubic ft. capacity, working in May 1882, with the moderate consumption of 21·45 cwt. of coke per ton of pig.

The case of No. 4 furnace, as working in November 1881 is that

of one working abnormally—as indeed is that of No. 3 in the same month; but of the two No. 4 was the worse. The Table clearly shows how the abnormal results were due to the conversion of carbonic acid into carbonic oxide at the expense of fuel introduced into the furnace. The abnormal condition arose from a cause at that time wholly unsuspected, but which proved a few months later to be the too close proximity of the tuyeres to each other, from nose to nose. The explanation of this was fully given before the Institution at Leeds in August last (see Proceedings, 1882, p. 279). It is unnecessary, and indeed beyond the scope of this paper, to go into that matter further.

It will be noticed that, in the investigation the results of which are tabulated in Table K, p. 134, there is only one case, that of Nos. 1 and 2 furnaces in May 1882, which affords an instance of *less* weight of carbon being transferred from the condition of carbonic acid to that of carbonic oxide than was actually contained in the limestone. There was really consumed, per ton of pig iron, only 11·16 cwt. of limestone, containing 3 per cent. of foreign matter; or 10·82 cwt. of pure carbonate of lime. Now 10·82 cwt. of carbonate of lime contains $10{\cdot}82 \times \frac{6}{50} = 1{\cdot}30$ cwt. of carbon; whereas the carbon absorbed from the coke was only 1·15 cwt. If this calculation could be relied upon as strictly accurate, such a result would point to the conclusion that it is possible to expel some of the carbonic acid from limestone without absorbing carbon from coke. And such a conclusion would be by no means improbable, if it be borne in mind that all generation of carbonic acid, due to the reaction of carbonic oxide on the calcined ironstone, was effectually lifted above the uppermost zone or region of red-hot coke; and also that the limestone, as it approached that zone, before actually entering it, would have passed through a red-hot atmosphere of gases emerging from the red-hot region of coke below, and might thus have parted with a superficial layer of its contained carbonic acid. No such positive conclusion can be drawn in this case, since the errors of calculation nearly equal the slight difference thus discovered; but certain it is that the working in May of Nos. 1 and 2 furnaces (of 33,400 and 35,013 cub. ft. capacity respectively) has shown the possibility of maintaining in the condition of carbonic acid the whole amount of

that gas produced by the reaction of carbonic oxide on the peroxide of iron contained in the calcined ironstone. No more mischief in fact was done, in the way of absorption of carbon by subsequent reaction between carbonic acid and carbon in coke, than was due to the evolution of carbonic acid from the limestone in immediate contact with red-hot coke. Even the larger pieces of ironstone, which would doubtless find their way into the furnace, were, under the favourable circumstances of that month's working, prevented from descending undecomposed into the red-hot coke region; to which result the large size of the furnaces must have materially contributed. At the same time it is possible that there was, during the month of May 1882, an exceptional freedom from bulky pieces of ironstone. In a slightly smaller furnace the same result might be accomplished by properly breaking up the larger pieces of ironstone, so as to ensure their reduction to the core in regions above the region of red-hot coke. But neither in larger nor smaller furnaces will it be possible to prevent the mischief done by the evolution of carbonic acid from limestone; because its displacement can only take place (except to a trifling extent) at a red-hot temperature. Hence, in the main, the carbonic acid must be evolved in contact with red-hot coke; and the foregoing calculations have already indicated how serious a source of mischief is nascent carbonic acid under such conditions. It has already been compared to a flow of carbonic acid turned on from a tap; but this does not represent all the mischief done, for it would appear that the decomposition of $12\frac{1}{2}$ cwt. of limestone (carbonate of lime) requires 1·88 cwt. of carbon burnt into carbonic oxide to effect the displacement of the gas. Now we have already seen that the loss sustained in the blast furnace, by the absorption of 1·50 cwt. of carbon contained in $12\frac{1}{2}$ cwt. of carbonate of lime, amounts to

$\frac{8080 \times 1 \cdot 50}{2473} - 1 \cdot 50$	= 3·40 cwt.
Add further quantity needed for the decomposition of $12\frac{1}{2}$ cwt. of Carbonate of Lime	1·88 „
Total . .	5·28 „

We have thus a total loss of 5·28 cwt. of carbon to work upon in the direction of further economy, in cases where $12\frac{1}{2}$ cwt. of carbonate of lime are employed. In the case of Nos. 1 and 2 furnaces, according to the working in May 1882, this margin was reduced to $\frac{5 \cdot 28 \times 10 \cdot 82}{12 \cdot 50} = 4 \cdot 57$ cwt., because they consumed only 10·82 instead of 12·50 cwt. of carbonate of lime. Against this figure of 4·57 cwt. must be set off the consequences of the reduced quantity of air which would be passing into the furnace, if so much less fuel were employed. Let us proceed to calculate what the effect of this will be, and so ascertain the amount of carbon needed to be burnt at the tuyeres to supply the deficiency.

The removal of 4·57 cwt. of carbon burnt into carbonic oxide would involve a diminution of air as follows:—

	cwt.
The weight of oxygen to burn 4·57 cwt. carbon = $\frac{4 \cdot 57 \times 8}{6}$ =	6·09
Nitrogen for ditto = 6·09 × 3·33 = ...	20·28
Total air . .	26·37

The gases passing away at the tunnel-head would be reduced by the following amounts:—

	cwt.
Carbonic oxide = $4 \cdot 57 \times \frac{7}{3}$ = ...	10·66
Nitrogen	20·28
Total reduction . .	30·94

At 810° C. (the temperature of blast in May 1882) the loss, estimated as carbon burnt into carbonic oxide, corresponding to the diminished weight of air passing into the furnace, would be

$$\frac{26 \cdot 37 \times 810^\circ \times 0 \cdot 239}{2473} = 2 \cdot 07 \text{ cwt.}$$

On the other hand a less weight of gases passing away at the tunnel-head would mean less heat carried away, and therefore must be reckoned as a gain. There would be gained in this way

$$\frac{30 \cdot 94 \times 214^\circ \times 0 \cdot 237}{2473} = 0 \cdot 64 \text{ cwt.}$$

Hence, subtracting a gain of 0·64 cwt. from a loss of 2·07 cwt., the net loss due to diminished air and gases is measured by 1·43 cwt. of carbon burnt into carbonic oxide.

The saving by use of primarily calcined lime at Nos. 1 and 2 furnaces, under the same favourable conditions of materials and working which existed in May 1882, would have been as under:—

	cwt.
Carbon saved in furnace	4·57
Deduct loss from diminished heat carried in by blast, less the allowance for diminished heat carried away by escaping gases	1·43
Net gain possible . .	3·14

Seeing that this gain would be effected on the already low consumption of 16·60 cwt. of carbon per ton of pig-iron, it seems reasonable that a limit of consumption, in Cleveland blast furnaces, of 13·46 cwt. of carbon may yet be reached, or say about 15 cwt. of coke, containing 10 per cent. of ash, &c.

ce Working. (*See a*

xide (at 2473 units

from 55 to 145 cwts.

700°	750°	800°	1400°	1450°	1500°	1550°	1600°
371°	399°	427°	760°	788°	816°	843°	871°
1·97	2·12	2·27	4·05	4·19	4·34	4·48	4·63
2·15	2·31	2·48	4·42	4·57	4·73	4·89	5·05
2·33	2·50	2·68	4·78	4·95	5·12	5·30	5·46
2·51	2·70	2·89	5·14	5·33	5·52	5·71	5·88
2·69	2·90	3·10	5·51	5·71	5·91	6·11	6·31
2·87	3·09	3·31	5·88	6·09	6·30	6·52	6·73
3·05	3·28	3·51	6·25	6·47	6·70	6·93	7·15
3·23	3·47	3·72	6·62	6·85	7·09	7·34	7·57
3·41	3·66	3·92	6·99	7·23	7·49	7·75	7·99
3·59	3·86	4·13	7·35	7·61	7·88	8·15	8·41
3·77	4·05	4·34	7·72	8·00	8·27	8·56	8·83
3·95	4·24	4·55	8·09	8·38	8·67	8·97	9·25
4·13	4·43	4·75	8·46	8·76	9·06	9·38	9·67
4·31	4·62	4·96	8·83	9·14	9·46	9·79	10·09
4·49	4·82	5·16	9·19	9·52	9·85	10·19	10·51
4·67	5·01	5·37	9·56	9·90	10·25	10·60	10·93
4·85	5·20	5·58	9·93	10·28	10·64	11·01	11·35
5·03	5·40	5·78	10·30	10·66	11·04	11·42	11·77
5·21	5·60	5·99	10·66	11·04	11·43	11·82	12·20

Blast Furnace, by heat carried off by
n 121° C. to 538° C.

800°	850°	900°	950°	1000°
427°	454°	482°	510°	538°
3·07	3·26	3·47	3·67	3·87
3·27	3·48	3·70	3·91	4·12
3·47	3·70	3·93	4·15	4·38
3·68	3·92	4·16	4·40	4·64
3·88	4·14	4·39	4·64	4·90
4·09	4·35	4·62	4·89	5·16
4·29	4·57	4·85	5·13	5·42
4·50	4·79	5·08	5·38	5·68
4·70	5·01	5·31	5·62	5·94
4·91	5·22	5·54	5·87	6·19
5·11	5·44	5·77	6·11	6·45
5·32	5·66	6·00	6·36	6·71
5·52	5·88	6·23	6·60	6·97
5·73	6·10	6·46	6·85	7·22
5·93	6·31	6·69	7·09	7·48
6·14	6·53	6·92	7·34	7·74
6·34	6·75	7·15	7·58	8·00
6·55	6·97	7·38	7·83	8·25
6·75	7·19	7·61	8·07	8·51
6·96	7·40	7·84	8·32	8·77
7·16	7·62	8·07	8·56	9·03
7·37	7·84	8·31	8·81	9·29
7·57	8·06	8·54	9·05	9·55
7·78	8·28	8·77	9·30	9·81
7·98	8·49	9·00	9·54	10·07
8·19	8·71	9·23	9·79	10·33

R. on of 1 cwt. increase of Heat. 43 cwt.	R. of 2½ cwt. increase of Heat. 3 cwt.	3 CWT. TRANSFER. Change resulting from conversion of 3 cwt. of C from CO_2 to CO, showing increase of C needed to make up loss of Heat. C in CO_2 from $Fe_2O_3 = 3·043$ cwt.		
Ratio.	Ratio.	Carbon per Ton of Pig Iron.	$\frac{CO_2}{CO}$ per Ton of Pig Iron.	Ratio.
		Cwts.	*Cwts.*	
1·55	·69	16·80	$\frac{16·654}{30·702}$	·54
1·35	·63	17·80	$\frac{16·654}{33·035}$	·50
1·19	·59	18·80	$\frac{16·654}{35·421}$	·47
1·07	·54	19·80	$\frac{16·654}{37·741}$	·44
·97	·51	20·80	$\frac{16·654}{40·061}$	·41
·88	·47	21·80	$\frac{16·654}{42·381}$	·39
·81	·45	22·80	$\frac{16·654}{44·70}$	·37
·76	·43	23·80	$\frac{16·654}{47·02}$	·36
·70	·40	24·80	$\frac{16·654}{49·40}$	·34
·66	·38	25·80	$\frac{16·654}{51·71}$	·32
·62	·37	26·80	$\frac{16·654}{54·03}$	·30
·58	·35	27·80	$\frac{16·654}{56·36}$	·29
·55	·34	28·80	$\frac{16·654}{58·69}$	·28
·52	·32	29·80	$\frac{16·654}{61·03}$	·27
·49	·31	30·80	$\frac{16·654}{63·36}$	·26
·47	·30	31·80	$\frac{16·654}{65·69}$	·25
·45	·29	32·80	$\frac{16·654}{68·03}$	·24
·44	·28	33·80	$\frac{16·654}{70·36}$	·236
·42	·27	34·80	$\frac{16·654}{72·69}$	·23
·40	·26	35·80	$\frac{16·654}{75·02}$	·22
·38	·25	36·80	$\frac{16·654}{77·36}$	·215
·37	·24	37·80	$\frac{16·654}{79·69}$	·208
·36	·236	38·80	$\frac{16·654}{82·03}$	·203
35	·23	39·80	$\frac{16·654}{84·36}$	·197
·34	·22	40·80	$\frac{16·654}{86·69}$	·191

),CO_2) has 12·50 $\times \frac{22}{50} = 5·5$ cwt. Carbonic Acid to the f Carbon peor uncombined.

TABLE D.—IDEAL FURNACE.

TABLE showing the Air to be admitted to the Tuyeres, and the Gases produced at the Tunnel head of a Blast Furnace, supposing all the Carbon consumed to do its extreme duty.

Carbon per ton of Pig Iron.	Escaping Gases.				Carbon for which Oxygen must be supplied by Blast.	Air of Blast.		
	Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.		Oxygen =1·33 Carbon.	Nitrogen =3·33 Oxygen.	Total. Oxygen + Nitrogen.
Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.
10	27·65	7·83	41·72	77·20	9·40	12·53	41·72	54·25
11	27·65	10·16	46·19	84·00	10·40	13·87	46·19	60·06
12	27·65	12·50	50·62	90·77	11·40	15·20	50·62	65·82
13	27·65	14·83	55·04	97·52	12·40	16·53	55·04	71·57
14	27·65	17·16	59·51	104·32	13·40	17·87	59·51	77·38
15	27·65	19·50	63·94	111·09	14·40	19·20	63·94	83·14
16	27·65	21·83	68·36	117·84	15·40	20·53	68·36	88·89
17	27·65	24·15	72·83	124·63	16·40	21·87	72·83	94·70
18	27·65	26·53	77·25	131·43	17·40	23·20	77·25	100·45
19	27·65	28·84	81·69	138·18	18·40	24·53	81·69	106·22
20	27·65	31·17	86·11	144·93	19·40	25·86	86·11	111·97
21	27·65	33·51	90·54	151·70	20·40	27·19	90·54	117·73
22	27·65	35·84	95·00	158·49	21·40	28·53	95·00	123·53
23	27·65	38·17	99·44	165·26	22·40	29·86	99·44	129·30
24	27·65	40·53	103·88	172·06	23·40	31·19	103·88	135·07
25	27·65	42·84	108·32	178·81	24·40	32·53	108·32	140·85
26	27·65	45·17	112·76	185·58	25·40	33·86	112·76	146·62
27	27·65	47·51	117·20	192·36	26·40	35·19	117·20	152·39
28	27·65	49·84	121·64	199·13	27·40	36·53	121·64	158·17
29	27·65	52·17	126·08	205·90	28·40	37·86	126·08	163·94
30	27·65	54·53	130·52	212·70	29·40	39·19	130·52	169·71
31	27·65	56·84	134·96	219·45	30·40	40·53	134·96	175·49
32	27·65	59·17	139·40	226·22	31·40	41·86	139·40	181·26
33	27·65	61·53	143·84	233·02	32·40	43·19	143·84	187·03
34	27·65	63·84	148·28	239·77	33·40	44·53	148·28	192·81
35	27·65	66·17	152·72	246·54	34·40	45·86	152·72	198·58

TABLE E.—½-Cwt. Transfer.

Table showing the changes of Fuel needed, of Air to be admitted, and of Gases produced, due to the transfer of ½ cwt. of Carbon from the state of Carbonic Acid to that of Carbonic Oxide.

Carbon per ton of Pig Iron. Ideal Work.	Carbon per ton of Pig Iron needed on ½ cwt. Transfer.	Escaping Gases.				Carbon absorbed. ·60 + ·50 cwt.	Carbon for which Oxygen must be supplied by Blast.	Air in Blast.		
		Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.			Oxygen =1·33 Carbon.	Nitrogen =3·33 Oxygen.	Total. Oxygen + Nitrogen.
Cwts.	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*
10	11·13	25·82	11·64	44·52	81·98	1·10	10·03	13·37	44·52	57·89
11	12·13	25·82	13·97	48·98	88·77	1·10	11·03	14·71	48·98	63·69
12	13·13	25·82	16·30	53·41	95·53	1·10	12·03	16·04	53·41	69·45
13	14·13	25·82	18·63	57·84	102·29	1·10	13·03	17·37	57·84	75·21
14	15·13	25·82	20·97	62·30	109·09	1·10	14·03	18·71	62·30	81·01
15	16·13	25·82	23·30	66·73	115·85	1·10	15·03	20·04	66·73	86·77
16	17·13	25·82	25·64	71·16	122·62	1·10	16·03	21·37	71·16	92·53
17	18·13	25·82	27·96	75·62	129·40	1·10	17·03	22·71	75·62	98·33
18	19·13	25·82	30·34	80·05	136·21	1·10	18·03	24·04	80·05	104·09
19	20·13	25·82	32·65	84·48	142·95	1·10	19·03	25·37	84·48	109·85
20	21·13	25·82	34·98	88·94	149·74	1·10	20·03	26·71	88·94	115·65
21	22·13	25·82	37·32	93·37	156·51	1·10	21·03	28·04	93·37	121·41
22	23·13	25·82	39·65	97·80	163·27	1·10	22·03	29·37	97·80	127·17
23	24·13	25·82	41·98	102·26	170·06	1·10	23·03	30·71	102·26	132·97
24	25·13	25·82	44·34	106·69	176·85	1·10	24·03	32·04	106·69	138·73
25	26·13	25·82	46·65	111·12	183·55	1·10	25·03	33·37	111·12	144·49
26	27·13	25·82	48·98	115·58	190·38	1·10	26·03	34·71	115·58	150·29
27	28·13	25·82	51·32	120·01	197·15	1·10	27·03	36·04	120·01	156·05
28	29·13	25·82	53·65	124·44	203·91	1·10	28·03	37·37	124·44	161·81
29	30·13	25·82	55·98	128·90	210·70	1·10	29·03	38·71	128·90	167·61
30	31·13	25·82	58·34	133·33	217·49	1·10	30·03	40·04	133·33	173·37
31	32·13	25·82	60·65	137·76	224·23	1·10	31·03	41·37	137·76	179·13
32	33·13	25·82	62·99	142·22	231·03	1·10	32·03	42·71	142·22	184·93
33	34·13	25·82	65·34	146·65	237·81	1·10	33·03	44·04	146·65	190·69
34	35·13	25·82	67·65	151·08	244·55	1·10	34·03	45·37	151·08	196·45

TABLE F.—1-CWT. TRANSFER.

TABLE showing the changes of Fuel needed, of Air to be admitted, and of Gases produced, due to the transfer of 1 cwt. of Carbon from the state of Carbonic Acid to that of Carbonic Oxide.

Carbon per ton of Pig Iron. Ideal Work.	Carbon per ton of Pig Iron needed on 1 cwt. Transfer.	Escaping Gases.				Carbon absorbed. ·60+1·00 cwt.	Carbon for which Oxygen must be supplied by Blast.	Air.		
		Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.			Oxygen =1·33 Carbon.	Nitrogen =3·33 Oxygen.	Total. Oxygen+Nitrogen.
Cwts.	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*
10	12·26	23·98	15·44	47·32	86·74	1·60	10·66	14·21	47.32	61·53
11	13·26	23·98	17·77	51·78	93·58	1·60	11·66	15·55	51·78	67·33
12	14·26	23·98	20·11	56·21	100·30	1·60	12·66	16·88	56·21	73·09
13	15·26	23·98	22·44	60·63	107·05	1·60	13·66	18·21	60·63	78·84
14	16·26	23·98	24·77	65·10	113·85	1·60	14·66	19·55	65·10	84·65
15	17·26	23·98	27·11	69·53	120·62	1·60	15·66	20·88	69·53	90·41
16	18·26	23·98	29·44	73·99	127·37	1·60	16·66	22·22	73·99	96·21
17	19·26	23·98	31·76	78·42	134·16	1·60	17·66	23·55	78·42	101·97
18	20·26	23·98	34·14	82·85	140·97	1·60	18·66	24·88	82·85	107·73
19	21·26	23·98	36·45	87·27	147·70	1·60	19·66	26·21	87·27	113·48
20	22·26	23·98	38·78	91·73	154·49	1·60	20·66	27·55	91·73	119·28
21	23·26	23·98	41·12	96·17	161·27	1·60	21·66	28·88	96·17	125·05
22	24·26	23·98	43·45	100·59	168·02	1·60	22·66	30·21	100·59	130·80
23	25·26	23·98	45·78	105·06	174·82	1·60	23·66	31·55	105·06	136·61
24	26·26	23·98	48·14	109·49	181·61	1·60	24·66	32·88	109·49	142·37
25	27·26	23·98	50·45	113·91	188·34	1·60	25·66	34·21	113·91	148·12
26	28·26	23·98	52·78	118·38	195·14	1·60	26·66	35·55	118·38	153·93
27	29·26	23·98	55·12	122·81	201·91	1·60	27·66	36·88	122·81	159·69
28	30·26	23·98	57·45	127·23	208·66	1·60	28·66	38·21	127·23	165·44
29	31·26	23·98	59·78	131·70	215·46	1·60	29·66	39·55	131·70	171·25
30	32·26	23·98	62·14	136·13	222·25	1·60	30·66	40·88	136·13	177·01
31	33·26	23·98	64·45	140·55	228·98	1·60	31·66	42·21	140·55	182·76
32	34·26	23·98	66·78	145·02	235·78	1·60	32·66	43·55	145·02	188·57
33	35·26	23·98	69·14	149·45	242·57	1·60	33·66	44·88	149·45	194·33

TABLE G.—1½-Cwt. Transfer.

Table showing the changes of Fuel needed, of Air to be admitted, and of Gases produced, due to the transfer of 1½ cwt. of Carbon from the state of Carbonic Acid to that of Carbonic Oxide.

Carbon per ton of Pig Iron. Ideal Work.	Carbon per ton of Pig Iron needed on 1½ cwt. Transfer.	Escaping Gases.				Carbon absorbed. ·60 + 1·50 cwts.	Carbon for which Oxygen must be supplied by Blast.	Air.		
		Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.			Oxygen = 1·33 Carbon.	Nitrogen = 3·33 Oxygen.	Total. Oxygen + Nitrogen.
Cwts.	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*
10	13·4	22·15	19·27	50·18	91·60	2·10	11·30	15·07	50·18	65·25
11	14·4	22·15	21·61	54·61	98·37	2·10	12·30	16·40	54·61	71·01
12	15·4	22·15	23·94	59·04	105·13	2·10	13·30	17·73	59·04	76·77
13	16·4	22·15	26·27	63·50	111·92	2·10	14·30	19·07	63·50	82·57
14	17·4	22·15	28·61	67·93	118·69	2·10	15·30	20·40	67·93	88·33
15	18·4	22·15	30·94	72·36	125·45	2·10	16·30	21·73	72·36	94·09
16	19·4	22·15	33·26	76·82	132·23	2·10	17·30	23·07	76·82	99·89
17	20·4	22·15	35·58	81·25	138·98	2·10	18·30	24·40	81·25	105·65
18	21·4	22·15	37·96	85·68	145·79	2·10	19·30	25·73	85·68	111·41
19	22·4	22·15	40·27	90·14	152·56	2·10	20·30	27·07	90·14	117·21
20	23·4	22·15	42 60	94·57	159·32	2·10	21·30	28·40	94·57	122·97
21	24·4	22·15	44·94	99·00	166·09	2·10	22·30	29·73	99·00	128·73
22	25·4	22·15	47·27	103·46	172·88	2·10	23·30	31·07	103·46	134·53
23	26·4	22·15	49·60	107·89	179·64	2·10	24·30	32·40	107·89	140·29
24	27·4	22·15	51·96	112·32	186·43	2·10	25·30	33·73	112·32	146·05
25	28·4	22·15	54·27	116·78	193·20	2·10	26·30	35·07	116·78	151·85
26	29·4	22·15	56·60	121·21	199·96	2·10	27·30	36·40	121·21	157·61
27	30·4	22·15	58·94	125·64	206·73	2·10	28·30	37·73	125·64	163·37
28	31·4	22·15	61·26	130·10	213·51	2·10	29·30	39·07	130·10	169·17
29	32·4	22·15	63·59	134·53	220·27	2·10	30·30	40·40	134·53	174·93
30	33·4	22·15	65·93	138·96	227·04	2·10	31·30	41·73	138·96	180·69
31	34·4	22·15	68·26	143·42	233·83	2·10	32·30	43·07	143·42	186·49
32	35·4	22·15	70·59	147·85	240·59	2·10	33·30	44·40	147·85	192·25

TABLE H.—2-CWT. TRANSFER.

TABLE showing the changes of Fuel needed, of Air to be admitted, and of Gases produced, due to the transfer of 2 cwt. of Carbon from the state of Carbonic Acid to that of Carbonic Oxide.

Carbon per ton of Pig Iron. Ideal Work.	Carbon per ton of Pig Iron needed on 2 cwt. Transfer.	Escaping Gases.				Carbon absorbed. ·60+2·00 cwts.	Carbon for which Oxygen must be supplied by Blast.	Air.		
		Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.			Oxygen =1·33 Carbon.	Nitrogen =3·33 Oxygen.	Total. Oxygen + Nitrogen.
Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.
10	14·53	20·32	23·08	52·98	96·38	2·60	11·93	15·91	52·98	68·89
11	15·53	20·32	25·41	57·40	103·13	2·60	12·93	17·24	57·40	74·64
12	16·53	20·32	27·75	61·84	109·91	2·60	13·93	18·57	61·84	80·41
13	17·53	20·32	30·08	66·30	116·70	2·60	14·93	19·91	66·30	86·20
14	18·53	20·32	32·41	70·73	123·46	2·60	15·93	21·24	70·73	91·97
15	19·53	20·32	34·74	75·16	130·22	2·60	16·93	22·57	75·16	97·73
16	20·53	20·32	37·07	79·62	137·01	2·60	17·93	23·91	79·62	103·53
17	21·53	20·32	39·39	84·05	143·76	2·60	18·93	25·24	84·05	109·29
18	22·53	20·32	41·77	88·48	150·57	2·60	19·93	26·57	88·48	115·05
19	23·53	20·32	44·08	92·94	157·34	2·60	20·93	27·91	92·94	120·85
20	24·53	20·32	46·41	97·37	164·10	2·60	21·93	29·24	97·37	126·61
21	25·53	20·32	48·75	101·80	170·87	2·60	22·93	30·57	101·80	132·37
22	26·53	20·32	51·08	106·26	177·66	2·60	23·93	31·91	106·26	138·17
23	27·53	20·32	53·41	110·69	184·42	2·60	24·93	33·24	110·69	143·93
24	28·53	20·32	55·77	115·12	191·21	2·60	25·93	34·57	115·12	149·69
25	29·53	20·32	58·07	119·58	197·97	2·60	26·93	35·91	119·58	155·49
26	30·53	20·32	60·40	124·01	204·73	2·60	27·93	37·24	124·01	161·25
27	31·53	20·32	62·73	128·43	211·48	2·60	28·93	38·57	128·43	167·00
28	32·53	20·32	65·06	132·90	218·28	2·60	29·93	39·91	132·90	172·81
29	33·53	20·32	67·40	137·32	225·04	2·60	30·93	41·24	137·32	178·56
30	34·53	20·32	69·73	141·75	231·80	2·60	31·93	42·57	141·75	184·32
31	35·53	20·32	72·06	146·22	238·60	2·60	32·93	43·91	146·22	190·13

TABLE I.—2½-CWT. TRANSFER.

TABLE showing the changes of Fuel needed, of Air to be admitted, and of Gases produced, due to the transfer of 2½ cwt. of Carbon from the state of Carbonic Acid to that of Carbonic Oxide.

Carbon per ton of Pig Iron. Ideal Work.	Carbon per ton of Pig Iron needed on 2½ cwt. Transfer.	Escaping Gases.				Carbon absorbed. ·60+2·50 cwts.	Carbon for which Oxygen must be supplied by Blast.	Air.		
		Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.			Oxygen =1·33 Carbon.	Nitrogen =3·33 Oxygen.	Total. Oxygen+Nitrogen.
Cwts.	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*
10	15·67	18·48	26·90	55·81	101·19	3·10	12·57	16·76	55·81	72·57
11	16·67	18·48	29·24	60·24	107·96	3·10	13·57	18·09	60·24	78·33
12	17·67	18·48	31·57	64·70	114·75	3·10	14·57	19·43	64·70	84·13
13	18·67	18·48	33·90	69·13	121·51	3·10	15·57	20·76	69·13	89·89
14	19·67	18·48	36·24	73·56	128·28	3·10	16·57	22·09	73·56	95·65
15	20·67	18·48	38·57	78·02	135·07	3·10	17·57	23·43	78·02	101·45
16	21·67	18·48	40·89	82·45	141·82	3·10	18·57	24·76	82·45	107·21
17	22·67	18·48	43·21	86·88	148·57	3·10	19·57	26·09	86·88	112·97
18	23·67	18·48	45·59	91·31	155·38	3·10	20·57	27·42	91·31	118·73
19	24·67	18·48	47·90	95·77	162·15	3·10	21·57	28·76	95·77	124·53
20	25·67	18·48	50·23	100·20	168·91	3·10	22·57	30·09	100·20	130·29
21	26·67	18·48	52·57	104·63	175·68	3·10	23·57	31·42	104·63	136·05
22	27·67	18·48	54·90	109·09	182·47	3·10	24·57	32·76	109·09	141·85
23	28·67	18·48	57·23	113·52	189·23	3·10	25·57	34·09	113·52	147·61
24	29·67	18·48	59·56	117·98	196·02	3·10	26·57	35·43	117·98	153·41
25	30·67	18·48	61·89	122·41	202·78	3·10	27·57	36·76	122·41	159·17
26	31·67	18·48	64·23	126·84	209·55	3·10	28·57	38·09	126·84	164·93
27	32·67	18·48	66·56	131·30	216·34	3·10	29·57	39·43	131·30	170·73
28	33·67	18·48	68·89	135·73	223·10	3·10	30·57	40·76	135·73	176·49
29	34·67	18·48	71·22	140·16	229·86	3·10	31·57	42·09	140·16	182·25

TABLE J.—3-CWT. TRANSFER.

TABLE showing the changes of Fuel needed, of Air to be admitted, and of Gases produced, due to the transfer of 3 cwt. of Carbon from the state of Carbonic Acid to that of Carbonic Oxide.

Carbon per ton of Pig Iron. Ideal Work.	Carbon per ton of Pig Iron needed on 3 cwt. Transfer.	Escaping Gases.				Carbon absorbed. ·60+3·00 cwts.	Carbon for which Oxygen must be supplied by Blast.	Air.		
		Carbonic Acid.	Carbonic Oxide.	Nitrogen.	Total.			Oxygen =1·33 Carbon.	Nitrogen =3·33 Oxygen.	Total. Oxygen+Nitrogen.
Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.
10	16·80	16·65	30·71	58·61	105·97	3·60	13·20	17·60	58·61	76·21
11	17·80	16·65	33·04	63·04	112·73	3·60	14·20	18·93	63·04	81·97
12	18·80	16·65	35·37	67·50	119·52	3·60	15·20	20·27	67·50	87·77
13	19·80	16·65	37·71	71·93	126·29	3·60	16·20	21·60	71·93	93·53
14	20·80	16·65	40·04	76·36	133·05	3·60	17·20	22·93	76·36	99·29
15	21·80	16·65	42·37	80·82	139·84	3·60	18·20	24·27	80·82	105·09
16	22·80	16·65	44·70	85·25	146·60	3·60	19·20	25·60	85·25	110·85
17	23·80	16·65	47·02	89·68	153·35	3·60	20·20	26·93	89·68	116·61
18	24·80	16·65	49·36	94·14	160·15	3·60	21·20	28·27	94·14	122·41
19	25·80	16·65	51·71	98·57	166·93	3·60	22·20	29·60	98·57	128·17
20	26·80	16·65	54·03	102·99	173·67	3·60	23·20	30·93	192·99	133·92
21	27·80	16·65	56·36	107·46	180·47	3·60	24·20	32·27	107·46	139·73
22	28·80	16·65	58·69	111·89	187·23	3·60	25·20	33·60	111·89	145·49
23	29·80	16·65	61·03	116·32	194·00	3·60	26·20	34·93	116·32	151·25
24	30·80	16·65	63·36	120·80	200·81	3·60	27·20	36·27	120·80	157·07
25	31·80	16·65	65·69	125·21	207·55	3·60	28·20	37·60	125·21	162·81
26	32·80	16·65	68·03	129·64	214·32	3·60	29·20	38·93	129·64	168·57
27	33·80	16·65	70·36	134·10	221·11	3·60	30·20	40·27	134·10	174·37
28	34·80	16·65	72·69	138·53	227·87	3·60	31·20	41·60	138·53	180·13
29	35·80	16·65	75·02	142·95	234·62	3·60	32·20	42·93	142·95	185·88

Date . . . No. of Furnace .	ge).	MAY 1882. Nos. 3 and 4 (average).	NOVEMBER 1881. No. 4.
Capacity in cubic f	34206	20454	20454
Chemical compositio			
Ratio, by weight, o	90	Calculated 0·59	Calculated 0·37
Average temperatu		800°	727°
Temperature of esc		305°	356°
Coke consumed per		21·45	24·98
Ash in the Coke, c	.)	2·10 (9·79 per cent.)	2·22 (8·91 per cent.)
Carbon consumed p		19·35	22·76
Carbon from Lime	aO, CO_2)	1·33 (11·40 − ·34 = 11·06 CaO, CO_2)	1·43 (12·32 − ·43 = 11·89 CaO, CO_2)
Transfer Curve to consumption mu		2·00	3·00
Total heat carried into Carbonic O		7·50	7·87
Actual Carbon of		19·35	22·76
Total t		26·85	30·63
Heat carried away into Carbonic O		3·75	5·08
Deposited Carbon,		·60	·60
Carbon absorbed CO; (CO_2 + C		2·00	3·00
Extra Carbon nee to the formula		4·54	6·80
Carbon needed for		1·66	1·79
Carbon remaining of C transferred		4·04	3·04
Carbon burnt into of Pig Iron .		6·67	6·67
Carbon for sundri		3·44	3·44
Carbon for meltin purposes; the b according to M.		0·00	0·00
Total		26·70	30·42
		+·15	+·21
Total		26·85	30·63

Abstract of Discussion.

The CHAIRMAN (GEORGE B. RENNIE, Esq.) said he was sure the members would all think with him that Mr. Cochrane's paper was one of the most valuable contributions that had been made to the Proceedings of the Institution. The vast amount of information he had given, and the great care he had displayed in preparing the numerous tables, for the purpose of presenting his ideas as to the proper way of working furnaces, would render the paper most valuable to all who were interested in the matter. He would first ask Mr. Cochrane if he had any additional remarks to make before the discussion began.

Mr. COCHRANE said he might have spared himself the trouble of asking his readers to assume that all the carbon in the hearth of a blast furnace was turned into carbonic oxide (p. 94), had he seen an article in *Iron* of the 5th of January (vol. 21, p. 19). There it was clearly shown that carbon, in the presence of a blast such as existed in a blast furnace, must be converted into carbonic oxide, and could not be converted into carbonic acid; for it appeared, by some experiments of Deville, that dissociation of carbonic acid took place at a temperature of from 1200° to 1300° C. Hence it was utterly impossible for carbonic acid to exist in the hearth of a blast furnace; for immediately the gas was exposed to the temperature reigning in the hearth dissociation would take place, and the carbonic acid be instantly resolved into oxygen and carbonic oxide. If any illustration were needed, he would point to the behaviour of an ordinary fire on a frosty night, when the blue flame due to combustion of carbonic oxide was seen at a distance of an inch or two, according to the intensity of combustion, from the fuel which was generating it; showing that the carbonic oxide could not burn until it got some distance away from the fuel, and was so far cooled as would enable it to receive the additional amount of oxygen needed to convert it into carbonic acid. So there was the seeming paradox (as described in the article) that carbon burned into carbonic oxide gave a far higher *temperature* than could possibly be obtained from carbon burned into carbonic acid, although the latter developed about 3½ times the total

quantity of heat which was capable of being generated by the former.

While engaged in working out the tables which he had presented to the meeting, he had received from Vienna an account of a paper read by Mr. Bell, expressing his astonishment at the small amount of fuel with which the charcoal furnaces of Austria were able to produce a ton of pig iron, and discussing seriously, but without any practical result, the question of the relative merits of carbon in the shape of charcoal or coke. He himself could not help thinking that Mr. Bell had overlooked one fact in his previous calculations, laborious and highly to be valued as they were—indeed without those calculations he himself could not possibly have taken the stride he hoped he had taken in the present paper. Mr. Bell had long ago made up his mind, that when the escaping gases gave two volumes of carbonic oxide to one volume of carbonic acid, no further improvement was possible in a blast furnace, at any rate in the Cleveland district. He seemed never to have contemplated the possibility of getting rid of the carbonic acid altogether from the region where it was detrimental, and not allowing it to interfere with the process of manufacture. Hence, notwithstanding the merit he was entitled to claim for indicating the way in which blast furnaces work, he had stopped short for a time in the path of progress, and needed someone else to point out the difficulty and suggest the means of overcoming it. With reference to the breaking up of ironstone (p. 112), let not members suppose that by proceeding simply to break the ironstone, in furnaces of small dimensions, they were going to do the slightest good to themselves. What he meant to say was, that with a furnace of large dimensions, say about 35,000 c. ft., it might be possible by breaking the large pieces of ironstone to secure its perfect reduction before it reached the dangerous region of red-hot coke; but if anyone thought that by breaking the ironstone in small furnaces he was going to accomplish the same result he would be greatly mistaken, because the red-hot region was so near the top of the furnace that, whether the ironstone was put in large or small, it would reach that region before its reduction was complete.

He would now refer to a communication he had received from Mr. Stead of Middlesbrough, which went to show that it was

possible Mr. Bell might have been mistaken in his mode of estimating the consumption of coke in a blast furnace. At the Leeds meeting, speaking of No. 3 Furnace at Ormesby, which, in March 1881, was using 24·15 cwt. of coke while working abnormally, Mr. Bell stated that the amount must be wrong; that it could not be using more than 22·35 cwt. This led him (Mr. Cochrane) to suspect that there must be something wrong in Mr. Bell's calculations, because of two factors in a problem, he was attempting to predicate the amount of the one from knowledge only of the other. All the knowledge he possessed was from the analysis of the gases escaping from the furnace; and yet, not knowing at all what quantity of coke was being consumed in the furnace, he went so far as to say that he (Mr. Cochrane) was 1·80 cwt. out in his record in the above-named instance and 2·63 cwt. in another (see page 315, Proceedings 1882). He himself knew, however, that he was correct in his record, and that the furnace was working abnormally. He immediately suspected therefore that there was something wrong in Mr. Bell's method; and, notwithstanding the risk he ran in not appearing to be able to answer Mr. Bell, he declined to do so at that meeting, but he mentally pledged himself to undertake the task of answering him once for all if it were possible to do so. Now Mr. Stead, in endeavouring to calculate, by Mr. Bell's method, the consumption of coke in a blast furnace from a mere analysis of the gases, had brought out two distinct results. He stated that if he considered everything to be working perfectly in the furnace, and the stone to be perfectly calcined, he arrived at 20·56 cwt. of coke per ton of pig. But there was no ironstone perfectly calcined; therefore he must allow 5 per cent. carbonic acid on that account, and so he arrived at the result of 22·2 cwt.—nearly 1¾ cwt. difference. This difference might be considered a very wide one, because the present paper was discussing tenths of cwts., and here there were whole cwts. being quietly allowed for. Yet Mr. Stead, after making all those allowances, was short by 1·14 cwt. of the actual fact. Mr. Stead's minimum was 20·56 cwt., while the real consumption was 24·12 cwt.: showing how wide of the actual mark the results of that mode of calculating the consumption of fuel in blast furnaces might prove to be.

Mr. J. E. STEAD said that Mr. Cochrane had stated pretty correctly what he had communicated to him; but he might be permitted to say that his object had been partly to defend Mr. Bell, and partly to express a doubt (he was not positive on the subject) whether Mr. Bell had taken account of the ironstone being imperfectly calcined. In some of his papers Mr. Bell had assumed that the ironstone had been perfectly calcined; and he (Mr. Stead) then pointed out what a great difference this would make in the calculation. Mr. Bell, as well as himself, would agree with Mr. Cochrane, that from a mere analysis of the gases, giving simply the ratio of carbonic oxide to carbonic acid, it was utterly impossible to arrive at the amount of coke being used in a furnace. Clearly it was also necessary to make an estimate of the weight of blast entering the furnace. Fortunately the very analysis of the escaping gases itself gave them that very thing: it not only gave the carbonic acid and the carbonic oxide, but it gave the nitrogen and the oxygen. Then, in estimating the quantity of carbon consumed in a blast-furnace, they did not need to look at the coke account first, but they commenced by looking at the nitrogen and the oxygen, and by calculating precisely how much oxygen must have been blown into the furnace with the amount of nitrogen shown in the analysis. That was deducted from the total oxygen, and the remainder was the amount of oxygen put into the top of the furnace. From this was calculated the weight of escaping gases per ton of pig, and then, from the weight of those gases, they could find the consumption of carbon; as would be seen from the figures below, which he had communicated to Mr. Cochrane, and which would speak for themselves.* The

* Calculations showing coke-yield, from analyses given in Mr. Cochrane's paper of gases at Ormesby Furnaces.

Analysis.	Per cent.	Percentage of Carbon.	Percentage of Oxygen.
N	54·80		
CO_2	13·42	3·66	9·76
CO	31·66	13·57	18·09
H	0·12		
	100·00	17·23	27·85

oxygen put in at the top of the furnace was a very constant quantity, and they could really calculate to within ½ cwt. the actual amount

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Assume the air to contain as follows:—

	Per cent.
N	76·5
O	23·4
H	0·1
	100·0

We then see that 54·8 cwt. of nitrogen in the gas must have been associated with $\frac{23 \cdot 4 \times 54 \cdot 80}{76 \cdot 5} = 16 \cdot 76$ cwt. of oxygen: and this leaves $27 \cdot 85 - 16 \cdot 76 = 11 \cdot 09$ cwt. of oxygen, in each 100 cwt. of gas, which must have been derived from the material charged at the top of the furnace, *i.e.* the limestone and ore.

Now, as the quantity of this oxygen may be taken as very nearly constant, we calculate the carbon from that, and not from the ratio of CO to CO_2.

As there is no statement of the quantity of limestone used in this case, we will assume that about 12 cwt. was charged per ton of pig.

We then have:—

Oxygen from ore ($Fe_2O_3 - SiO_2 - P_2O_5$)	= 9·00	cwt. per ton of pig.
Oxygen from CO_2 in limestone	= 3·49	" "
	12·49	

This is assuming that the stone is perfectly calcined.

Since there is thus 12·49 cwt. oxygen put in at the top, per ton of pig, it is easy to calculate what weight of gases per ton is given off, and from that to find the yield of coke.

Now we have seen above that there are 11·09 cwt. of oxygen put in at the top for every 100 cwt. of escaping gas. Therefore the weight of gas per ton of pig $= \frac{100 \times 12 \cdot 49}{11 \cdot 09} = 112 \cdot 6$ cwt.

As 100 cwt. of the gas contains 17·23 cwt. carbon, 112·6 cwt. must contain 19·40 cwt. carbon, to which must be added 0·60 cwt. for carbon absorbed in 20 cwt. pig, while 1·31 cwt. must be deducted for carbon in the limestone. We have thus a total of 18·69 cwt. carbon from coke, or 20·56 cwt. coke per ton.

This result is too low, and the difference must be due to the ore being imperfectly calcined, or to the analysis not being an average one.

of coke being consumed. He had frequently done so, and had obtained very close results indeed by that method. But in the case of Cleveland ironstone they were obliged to ascertain precisely how much carbonic acid was left in the calcined ironstone, before they estimated the results. If, in calculating the amount of coke, they did not take into consideration the question of the stone being perfectly calcined, the results might come out, as Mr. Cochrane had said, very much lower than the actual facts. He had assumed for the sake of argument, in writing to Mr. Cochrane, that the stone in his case contained 5 per cent. of carbonic acid. It did not generally contain so much; but it was a very easy matter for a chemist to get an analysis of the ironstone, before it went into the furnace, and then, having an analysis of the ironstone and an analysis of the limestone, and knowing the composition of the pig iron, and the quantity of slag per ton approximately, he would have all the factors for calculating precisely the amount that was put into the top of the furnace. In writing to Mr. Cochrane his object had been mainly to defend gas analysis; for he believed he had done more than almost anybody (after Mr. Bell) in gas analysis, and in the improvement

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The writer finds that 5% carbonic acid often remains in calcined Cleveland stone; or say 2¼ cwt. per ton of pig. Assuming that this has been the case, there would be an increase of carbon and oxygen charged as follows :—

Carbon . . .	0·61 cwt. per ton of pig.	
Oxygen (1·64 − 0·41) .	1·23	„ „

The total oxygen charged at the top would thus amount to :—

Oxygen as before given	= 12·49 cwt. per ton of pig.	
Extra oxygen from ironstone =	1·23	„ „
Total .	13·72	

The total weight of gases would therefore be $\frac{13\cdot72 \times 100}{11\cdot09} = 123\cdot7$ cwt. per ton of pig; and these contain 17·23 per cent. of carbon, or $\frac{17\cdot23 \times 123\cdot7}{100} =$ 21·3 cwt. per ton of pig. Hence total carbon from coke $= 21\cdot3 + 0\cdot60 - (0\cdot61 + 1\cdot31) = 19\cdot98$ cwt. Total coke $= 19\cdot98 \times \frac{10}{9} = 22\cdot20$ cwt. per ton of pig.

of apparatus for testing blast-furnace gases. And although Mr. Cochrane had not altogether condemned gas analysis, he had made such observations upon it as seemed to make it necessary to say something in its defence.

Mr. COCHRANE said he had not called in question the value of gas analysis, except when it was taken *per se*. It should be taken in conjunction with the actual consumption of coke. That was the extent of the observation he had made.

Mr. I. LOWTHIAN BELL, F.R.S., said that absence from home and other occupations had rendered it, until the day before, highly improbable that he would be able to attend the meeting; and all the opportunity he had had of considering the facts detailed in the paper, and the battalions, or rather the armies of figures, which appeared in it, was during his journey from the north. He therefore trusted that anything in the observations he was about to make, which might seem of a somewhat imperfect character, would meet with the indulgence of the meeting. The paper, which was extremely elaborate, seemed to have for one of its objects to popularise an extremely learned work, namely that of his friend Professor Gruner on Blast Furnaces, which had been translated by Mr. Lewis Gordon, and was therefore accessible to anyone who felt an interest in the question. In so doing Mr. Cochrane had placed himself in rather a delicate position. He came before them, inferentially at all events, recommending the study of Gruner's work; but, although it had not been mentioned, Professor Gruner had done him (Mr. Bell) the honour of basing almost all the calculations contained in that volume upon his recorded experiments, and of confirming almost all his conclusions; so that Mr. Cochrane was recommending the book, while at the same time denouncing some of the very doctrines which the book had undertaken to expound.

The paper began (p. 93) by referring to opinions published nineteen years ago on the direct influence of the capacity of furnace on the cooling the gases. That story had been told over and over again. Of course, where a stream of comparatively cold material was

descending in a furnace and meeting an ascending stream of highly heated gases, the latter must necessarily have the temperature lowered. But this influence upon the temperature of the gases was far from being in a direct ratio to the capacity. He had shown this in 1869 by a curve published in the Journal of the Iron and Steel Institute, vol. I., p. 43. The curve began with a furnace of 6000 cub. ft. capacity, where the temperature of the escaping gases was 845° Fahr. In a furnace with a capacity of 11,600 cub. ft. the temperature of the gases was 610°; with 15,400 cub. ft. it was 595°; and with 25,500 cub. ft. it was 587°. Now, how did it happen that between 6000 cub. ft. and 11,600 cub. ft. the temperature had fallen 235°; and yet, with a further addition of even 14,000 cub. ft., practically the temperature of the gases had not fallen at all? The explanation he gave at the time—and Prof. Gruner entirely agreed with it—was that there were two foci of heat generation in every blast furnace. There was first the great evolution of heat proceeding from the admission of the blast at the tuyeres; and there was secondly a considerable evolution of heat at the top of the furnace itself. Mr. Cochrane appeared to express his dissent from that statement. Now he was quite aware that the experimental facts which went to prove that statement lay within very narrow limits; and this arose in the following way. Near the top of the furnace there were two processes going on: (1) the unburning of peroxide of iron, which meant an absorption of heat; and (2) the burning of carbonic oxide into carbonic acid, which meant an evolution of heat. Now if these two sides of the account were exactly the same, then of course there would be no focus of heat at the top of the furnace. But in addition to these, there was a secondary action of which Mr. Cochrane had taken no account whatever. When two equivalents of carbonic oxide came in contact either with heated oxide of iron or with heated metallic iron, a very curious reaction took place: these two equivalents of carbonic oxide were dissociated into one of carbonic acid and one of carbon, according to the equation $2\,CO = CO_2 + C$; and this was accompanied by evolution of heat. He admitted that, even with this addition, the balance of heat evolved was not a large one, *i.e.* as between evolution and absorption. Seeing

this, he determined that nothing short of an actual experiment on a blast furnace itself should satisfy him. The experiment was made as follows. After noting very carefully for some hours the average temperature of the gases as they issued from a blast furnace, which was performing its functions in the ordinary way (namely deoxidising ironstone with a considerable amount of chemical action), he withdrew all the ironstone and all the flux, and in their stead introduced the same weight of other materials (blast-furnace cinders and flints), in which, at all events near the top of the furnace, no action whatever due to chemical combination could take place. After allowing a sufficient time to elapse after making the change, so that the ironstone, which was already in progress of deoxidation, might be completely reduced, the temperature began to fall; and finally it fell something like 200° F. Having continued this for something like four hours, he then restored the ironstone and the flux as before, and as soon as the fresh ironstone had become sufficiently heated to permit the carbonic oxide to act upon the oxide of iron, the temperature began to rise, and speedily assumed its former intensity; and he could only say that with the exception of Mr. Cochrane himself, who appeared to dissent from him, every philosophical enquirer on the subject, with whom he had had an opportunity of conversing, had approved the soundness of the deduction he had made from that experiment.

The paper contained a great number of calculations as to the loss in carbon due to the heat of the escaping gases. But in the same way as the temperature remained pretty constant, after the capacity reached 11,000 or 12,000 c. ft., so also the waste of coke by loss of heat in the escaping gases remained pretty constant. He had calculated that in a cold-blast furnace fully 25 per cent. of the fuel was so lost in the gases; but in a hot-blast furnace of 6000 c. ft. the loss from that cause was under $4\frac{3}{4}$ cwt. per ton of pig; and when the capacity was 11,500 c. ft. the loss was 2·33 cwt., showing a saving of 0·44 cwt. of coke for each 1000 c. ft. increase of capacity. But with Mr. Cochrane's enormous furnace, the saving, as between 11,500 and 35,000 c. ft., instead of being 0·44 cwt. per 1000 c. ft. increase, dropped down to 0·064 cwt.; so that it was not above one-seventh

of what it was before. And here he would remark that a portion of the cooling might be due to the temperature of the ironstone, which at the Clarence Works was always used warm.

He would now touch upon the question of the value of chemical analysis, which the paper certainly seemed to depreciate.

In his opening remarks Mr. Cochrane had mentioned that he (Mr. Bell) had ventured at Leeds to dispute the quantity of coke that had been used in a particular furnace at a particular time, and had said that he (Mr. Bell) had no actual knowledge of the quantity of coke; but Mr. Cochrane had forgotten that—thanks to his own kindness and that of his brothers—the quantity of coke alleged to have been consumed in the furnace was accurately given at the time. The relative quantities of coke and ironstone, together with the "yield" of the latter, were stated; and he quite agreed that the amount of coke, as mentioned by Mr. Cochrane at the time, worked out to something like 24·5 cwt. per ton of pig, in the case of No. 3 Furnace. The analysis of the gases however showed the ratio of carbonic acid and carbonic oxide; and having that, and also the temperature of the blast, it was very easy to ascertain what was the heat equivalent of a unit of coke as burnt in that furnace under these conditions. He had before him a great many calculations of that kind. Thus in one example the heat derived from the combustion of carbon was found to be 3580 calories, while the blast contained 574 calories per unit of coke. Hence the equivalent in heat, for each unit of fuel burnt in that furnace, was 4154 units. It was almost as easy, by analysing the iron, and by considering all the actions which had taken place in the furnace, to determine, he would not say precisely, but very nearly, the quantity of heat required to smelt a given quantity of iron. Now if they had, say, 24 cwt. of coke per ton, and multiplied that by the heat equivalent obtained as above, that of course would give the quantity of heat actually developed per ton of pig. On the other side could be estimated the total quantity of heat required, as just explained, for the various operations of the furnace; and these two should approximately balance each other. But when he came to make that calculation, in the case referred to, instead of having, as he ought to have had, something like 89,000

units, due to the coke consumption, as stated to him, he had above 100,000 units; showing clearly that there was an excess of something like 2 cwt. of coke in the account given to him at the Ormesby Works. On the other hand, when he multiplied the heat-units per unit of coke by the quantity of coke calculated from the analysis of the gases (in respect of which, being a question of simple arithmetic, there ought to be no kind of dispute), he then found that the two sides of the account corresponded almost exactly. Mr. Cochrane indeed maintained that you could not, by an analysis of the gases, determine the quantity of carbon, and therefore the quantity of coke used; but in that he (Mr. Bell) differed entirely from him, as he should have the opportunity of showing before long.

The Tables C and D required, he imagined, very considerable modification and correction for practical use; because, every time the quantity of coke used per ton of pig was diminished, the quantity of air required was diminished also; and in order to make the tables of any value, a correction must be made on that account. This was rather an intricate calculation—so intricate indeed that he questioned whether the tables would be found to have the value which the author attached to them. But in all the tables there was also, in his opinion, a fundamental and a more serious error. Mr. Cochrane had ascertained the quantity of heat in a given weight of air at a given temperature, and he then proceeded, in order to convert that heat into its value in coke, to divide the given number by the number of calories evolved in converting 1 cwt. of carbon into carbonic oxide. The paper had taken 2473 as representing the heat-units or calories evolved by burning 1 cwt. carbon into carbonic oxide. Of course that was assuming that the air used upon that occasion was initially at freezing point—0° C. or 32° F. He admitted however that in similar calculations, knowing how many causes of disturbances there were, he had never gone to the refinement of considering what the initial temperature of the air was at the time. He always assumed it to be 32° F., although it was known that in fact it was very rarely 32°. But supposing, just for the sake of argument, that the atmosphere could have a temperature of 1000° F., *then* it was quite clear that to take 2473 as the

coefficient of heat-evolution would be most misleading. In like manner the paper assumed that the carbon was burnt to the state of carbonic oxide; but it was perfectly well known that in a blast-furnace a considerable quantity of it was burnt to carbonic acid; and if the tables were intended to show an ironmaster how much fuel he could save by increasing the temperature of the air from one point to the other, and generally to be a guide as to the saving of fuel, both the temperature of the blast and the state of oxidation of the carbon must be taken into account. Instead of the average coefficient of heat-evolution in a furnace being 2473, in point of fact it was about 4000; so that, taking Mr. Cochrane's example, p. 96, in which he made 7·09 cwt. of carbon to be saved by heating the blast from 0° C. to 816° C., the actual saving would be only 4·34 cwt. In all the tables that error prevailed.

On p. 99 the paper spoke of loss occasioned by interruption in charging the furnace. It was known quite well that when that took place the temperature of the gas began to rise, and that, as Mr. Cochrane had pointed out, the loss might be a very serious one. But that was only half the story. Immediately you ceased charging, the ratio of carbonic acid to carbonic oxide began to fall off, and in consequence Table C, formed upon the basis of that ratio, would, he apprehended, also be found to involve considerable error. With regard to that table, he saw that it was based upon the supposition that there could only be 6·043 cwt. of carbon converted into carbonic acid per ton of pig. Now in all his own calculations he had assumed that for every ton of iron made there might possibly be 6·78 cwt. of carbon so converted. The difference between them arose from Mr. Cochrane having overlooked the fact of the generation of carbonic acid from the dissociation of carbonic oxide, as he had explained above, p. 142; that it could be more than 6·043 cwt. was proved by the fact that in actual practice he had himself detected 6·52 cwt. of carbon as carbonic acid per ton of pig.

The paper further pointed out that they must always be careful to preserve the amount of carbon named by the writer in the form of carbonic acid, and that if the amount were diminished there was certain to be a loss. He admitted that at one time he entertained

the same opinion; but on considering the matter further he had altered his view. That quantity of carbonic acid could be materially diminished without loss; but its place must then be compensated for by heat in the blast. But while so acting they must take care that they preserved that relation between carbonic oxide and carbonic acid (2 of carbon as CO to 1 of carbon as CO_2), to which he had over and over again adverted, and in respect of which his friend, Mr. Cochrane, had just warned him that he had been entirely mistaken. Now it would take far too long a time to go into the very abstruse question of the action of charcoal furnaces, referred to in Mr. Cochrane's opening remarks. He had lately given some attention to this branch of the question, which he would make known before long. He was now dealing exclusively with Cleveland ironstone smelted in a Cleveland furnace, and with Durham or similar coke. As most of those present knew, carbonic acid, instead of being a reducing agent, was an oxidising agent. Carbonic oxide, on the other hand, was a strongly deoxidising or reducing agent; and the question was the point at which these antagonistic forces neutralised each other. He had determined by a great number of experiments that that position of neutrality was reached before the ratio became 1 of carbon as carbonic acid to 2 of carbon as carbonic oxide. Now it was no use laying down any law unless you were able to prove it by actual experiment; and the manner in which he proved that law was simply this. In the gases as they came from the blast furnace, having an approach to that condition (carbon as CO_2 : carbon as CO : : 1 : 2), he placed ironstone, and found that no reduction took place; was it extraordinary then that he should arrive at the conclusion that the moment these two gases reached that relation they were unable to act further on the ironstone in the furnace? He had been often at Mr. Cochrane's furnaces, and he again thanked that gentleman for the courteous and frank reception given to him, notwithstanding their differences upon this question. He had seen the furnace alluded to (No. 2), which was driven with the hottest blast in the world, and even there the proportion of carbonic acid to carbonic oxide was short of the quantity just referred to.

With regard to gas analyses, Mr. Cochrane had imported a new term, "transfer." He said in effect, "Supposing an atom of carbonic acid to come into contact with an atom of carbon, they would pass off as carbonic oxide; and yet there was no change in the quantity of carbon, none in the quantity of oxygen; hence your analysis cannot detect the loss of heat that has occurred." That was quite true; but Mr. Stead saw at once the fallacy involved in this statement, so far as concerned our inability to calculate the consumption of coke from the composition of the gases. It was not the carbon in the gases that was an indication of what was going on in the furnace in this respect, but it was the nitrogen. Mr. Cochrane himself would admit (so at least he inferred), "If you could only measure the atmospheric air that went into the bottom of the furnace, you would be all right—there would be no doubt about the matter then." But they could and they did measure it, by the analysis itself; and all the calculations of which he had made use were based on the fact that the quantity of atmospheric air was expressly and accurately determined by the quantity of nitrogen in the escaping gases. Therefore, when Mr. Cochrane said that you could not ascertain the quantity of coke used, of known composition, by the quantity of carbon and oxygen in the gases, he was altogether mistaken.

He had only just time to glance very hurriedly over the figures contained in the document alluded to by Mr. Stead, and handed in by him. He had no doubt the calculation was precisely the same as those employed by himself. From the series made use of on such occasions the following equation had been deduced:—

Let x be the total weight of carbon in the gases per ton of iron.

" O the total percentage of oxygen in the gases.

" N " " " nitrogen " "

" C the percentage of carbon in the gases.

" O_M the total oxygen brought in by the minerals per 20 units of pig.

$O - 0 \cdot 3112$ N the percentage of oxygen in the gases as far as it originates from ore and limestone, *i.e.* allowing for that derived from $0 \cdot 72$ per cent. of moisture — the assumed quantity in the blast.

On that assumption the equation in an abbreviated form was:—

$$x = \frac{C \times O_M}{O - 0 \cdot 3112\,N}$$

Of course such calculations as those in question were liable to disturbance by any carbon remaining in the ore after calcination. He could not suppose any such average quantity as that named by Mr. Stead could remain in the calcined ore. It would, he imagined, be much safer to suppose that 5 per cent. of the original carbonic acid remained unexpelled, in which case the carbon due to this cause could only amount to something under 0·2 cwt. per ton of iron made.

Mr. Cochrane had very early nailed his colours to the mast, as to what might be expected in the reduction of fuel in blast furnaces. He believed he was once so sanguine as to hope that he might make a ton of iron with 7·43 cwt. of coke; he afterwards stretched it to 13 cwt., and then to 17 cwt., and he was now oscillating between 15 cwt. and 17 cwt. On page 123, he pointed out the possibility, by calcining limestone, of saving 3 cwt. of coke per ton. He himself could not exactly follow the figures, but he was bound to admit that it was impossible to dissociate carbonate of lime without expenditure of heat; and one undoubtedly might infer that if he separated the carbonic acid from the lime before it went into the blast furnace he ought to save fuel. He had himself reasoned in that way, and had proceeded to put the matter to the test of experiment. Undoubtedly in small furnaces there was a small saving, but it never amounted to what it ought by calculation; and when he came to try it with large furnaces the saving was absolutely nil. He might be asked, "How does it happen that under the circumstances there is no saving?" Taking the quantity of limestone commonly used in blast furnaces, there were about 5000 calories absorbed in the dissociation of limestone—which, in point of fact, amounted to about 1¼ cwt. of coke only. But carbonic acid, as they all knew, even at atmospheric temperatures, united with lime with considerable readiness, and that readiness was greatly quickened when it united with lime at a temperature of 500° or 1000° Fahr. Hence the instant calcined lime was put into the furnaces, and met the hot gases, which

contained a considerable quantity of carbonic acid, it began to re-absorb carbonic acid from those gases, and absorption went on until the carbonate of lime arrived at a zone where the temperature sufficed for its dissociation. He should not be surprised indeed to find that it was entirely re-converted into carbonate of lime before it arrived at that point. Still it might be truly said, that the very union of the carbonic acid with lime ought to evolve as much heat as was absorbed in its subsequent dissociation. He granted that; but then it must be remembered that this evolution of heat began close to the very top of the furnace; and thus the gases had not time, before they had left the furnace, to communicate the heat so evolved to the stream of descending materials. That, at least, was the only way in which he could account for the want of economy by the use of calcined lime; and he had tried the experiment, not for a day or a week, but for months together, because the saving of even a hundred-weight of coke in a blast furnace was a matter of great importance. The paper said something (p. 112) about the advantage of the ironstone being broken small in certain cases, though it was not recommended by the writer. He himself would not go into that matter; but he believed that very little if any ironstone practically descended through a furnace in large masses. By the impregnation of the carbon, as he called it—that is, the dissociation of carbonic oxide into carbonic acid and carbon—minute particles of carbon were lodged in the interstices of every piece of ironstone, and gradually split up the ore into a black powder. He should be borne out by every practical ironmaster in saying that, while at the tuyeres they saw masses of unconsumed lime and of coke, they scarcely ever saw ironstone except as very coarse powder. Again, when they raked the material out of a furnace that had been blown out, they saw lumps of coke and of limestone, but not of ironstone; and this was simply because the ironstone had been split up, precisely in the way that lime split up when it was slaked with water. That was no theory, because he had over and over again placed pieces of ironstone in glass tubes, at various temperatures, over which he passed various mixtures of carbonic acid and carbonic oxide, so that he could watch their behaviour.

Mr. E. A. COWPER said, with reference to Mr. Bell's last remark, he might perhaps mention that the Marbella iron ore was often known to come out with the cinder, in unreduced lumps. In another case of an experiment with some large blocks of Cleveland ironstone, which had been thoroughly impregnated with carbon by means of hot carbonic oxide, they came out in sound hard lumps. Whether the same results would take place in a blast furnace he did not know; but the lumps in the experiment were thoroughly impregnated, and yet they had not gone to pieces. He fancied that, if more carbon were put into them, they might do so—somewhat in the manner in which some bricks in the Cleveland district had gone to pieces. He was inclined to think that it was partly owing to the bricks not being thoroughly burned; and that, containing, as they did, some iron, that iron continually absorbed the carbon from the gases until it swelled so far as to burst the bricks. Some of the bricks were nearly twice the thickness they had been originally. He might add that he was pleased at one thing Mr. Bell had said, namely that a *saving of* 1 *cwt. of coke in a blast furnace was of great importance.* Now the average consumption of coke per ton of pig, in the Cleveland district, was certainly as high as 22½ cwt.—he thought that Mr. Stead and Mr. Bell would agree with him in that; whereas at the furnaces of Mr. Cochrane, in 1882, the consumption was in two cases 18·34 and 18·45 cwt. only; showing the gigantic strides made by the introduction of very hot blast.

Mr. BELL said that Mr. Cowper's instance was quite intelligible. It was easy to conceive that chance pieces of ironstone might escape the action he had described. He was not speaking of one or two blocks, which Mr. Cowper or any other gentleman might have seen, but of the action as a whole; and he said that of 10,000 tons of ironstone passing through a blast furnace the probability was that 9999 would come out in the way he had mentioned.

Mr. STEAD asked leave to say a word in confirmation of what Mr. Bell had stated with reference to the splitting up of the ore. In the case of one furnace, at Ferry Hill, which had to be cooled down

with water, when almost completely filled, the material was drawn out at the bottom, and the stone was found to be in very small pieces—not more than a cubic inch, or two cubic inches at the outside.

Mr. ARTHUR PAGET said the original ground of the discussion between Mr. Bell and Mr. Cochrane appeared to be the plain fact whether a certain output of iron was produced under certain circumstances with a certain consumption of coke, or not. Now he ventured to suggest that this was a case in which the Institution might be of great value. If the question was still not absolutely settled, he ventured to suggest that the Institution might assist the two members, who, they were all aware, were discussing the matter solely with a view of increasing their knowledge and experience, and of enabling iron to be produced more cheaply. His suggestion would be that the Institution should appoint certain gentlemen to ascertain the plain fact; because if that quantity of iron was produced with the consumption of coke as stated, it appeared as if some of the theories required some correction.

Mr. COCHRANE, in reply, said that the first point dealt with by Mr. Bell, was that of the influence on the temperature of the gases due to increase of the furnace capacity from 11,500 to 25,000 c. ft.; and he inferred, from certain limited observations, that there was practically no difference due to the increased capacity of the furnace. He ventured to observe that there must be some other explanation of such a series of observations, because in the furnace of which he had given a description, of 35,000 c. ft. capacity, the temperature had been lowered to 352° F.; so that only 50° more would bring it down to one-half the temperature (600° F.) which was deemed by Mr. Bell to be a minimum temperature at the top of a blast furnace. That question was coupled with the old allegation of his friend Mr. Bell, that there was a zone or focus of heat at the top of the furnace, and that it mattered not how high the furnace was, because that zone of heat would follow it up, go as high as you would. It was that position as to which he made the sign of dissent

to which Mr. Bell had alluded. He simply meant that, as a matter of fact, whatever focus of heat there might be—he did not deny that in theory there was such a focus—it was possible to absorb that heat or a very large portion of it (in the present case nearly one-half), and make it available for saving fuel in the blast-furnace. If there was one point he had established more clearly than another, it was that this focus of heat had not followed him up from the furnace of 20,000 c. ft. to the furnace of 35,000 c. ft., but that he had left it down below, and had reduced the temperature of his gases to nearly one-half of what Mr. Bell had declared to be the minimum.

He had no intention whatever of "depreciating" gas analysis. It was stated in the paper distinctly that it was the taking of analyses alone and by themselves which he condemned. No one could predicate what was the coke consumed in a blast furnace from a mere analysis of the gases, whether from carbonic acid or carbonic oxide, or the oxygen; nor did he know how from the nitrogen you could deduce anything conclusive. For it was admitted on all hands that there was an enormous difference in value between carbon burned into carbonic acid and carbon burned into carbonic oxide. But on joining an equivalent of carbonic acid with an equivalent of carbon, and so converting it into carbonic oxide, the oxygen was left undiminished; and yet such an important change had taken place as this, that so much carbonic acid had been unburned, to convert it into carbonic oxide, and therefore had robbed the furnace of an enormous quantity of heat, without any disturbance in the proportion of oxygen. The oxygen remained undisturbed, but carbon had been absorbed, and the heat due to that absorption was absolutely lost.

As to the tables requiring considerable correction, he had made an observation, p. 120, as to slight inaccuracies which prevented his drawing any definite conclusion as to carbonate of lime being in some cases decomposed without doing mischief. But that was the veriest trifle, and he seriously hoped and confidently believed that there were no huge corrections to make, such as had been referred to when the meeting was told that the saving in a case referred to by Mr. Bell was not 7·09 cwt., but 4·34 cwt. He could not

understand how he could have balanced his accounts so nearly as he had done in the cases cited in Table K, p. 134, if they were 2·75 cwt. out in that important factor of his calculations. He could only repeat what he had said in the paper, that the weight of the blast, multiplied by the temperature and specific heat, and divided by the units of heat developed by a cwt. of carbon burnt into carbonic oxide, did represent the quantity of carbon which would replace the heat actually carried into the furnace by that weight of blast at that temperature.

With regard to the two volumes of carbonic oxide to one of carbonic acid, Mr. Bell still adhered to his statement, which indeed was perfectly correct, that when there was that proportion of carbonic acid to carbonic oxide, reduction of ore could no longer take place. But the object of his (Mr. Cochrane's) paper was to submit a means by which, whatever the proportion of carbonic acid to carbonic oxide in the escaping gases, the carbonic acid should not be allowed to interfere with the process of reduction; inasmuch as the process of reduction would go on in that upper region where Mr. Bell—he believed, as far as this was concerned, correctly—placed his focus of heat, would be completed there by itself, and would not come down into a region of red-hot coke, where the evolution of carbonic acid leads to the absorption of carbon, and interferes still further with the consumption of coke in the furnace.

The last observation he would make was as to the ironstone being split up within the furnace. Some years ago (Proceedings 1871, p. 167) he had submitted to the Institution the possibility of deoxidising the ironstone of Cleveland in separate chambers, so that the process of the blast furnace should be limited to melting the slag and iron. At that time he had regularly brought out tons of that ironstone exactly in the same shape in which it was put into the sort of cupola or temporary furnace that he erected; he had brought it out without being split up in the least, but perfectly deoxidised, and ready to be melted.

The CHAIRMAN said they would all agree with him that they ought to give Mr. Charles Cochrane a hearty vote of thanks for contributing

such an interesting paper, and eliciting such an excellent discussion as they had heard. He thought they ought also to thank Mr. Bell for having taken the trouble to come to town expressly for the purpose of giving them the benefit of his long experience and great knowledge with regard to blast furnaces.

ON THE ST. GOTHARD TUNNEL.

By Herr E. WENDELSTEIN, of Lucerne.

The present paper is intended to give a brief sketch of the methods employed in constructing and working the great Tunnel piercing the chain of the Alps on the line of the St. Gothard Railway. A plan of the district passed through by the tunnel is given in Fig. 1, Plate 6; and a section of the tunnel, with the overlying rocks, is given in Fig. 2, Plate 7. Of the approaches to the tunnel on either side, which possess many points of great interest, no account will be attempted in the present paper; but it is hoped that this may be given in a future communication, which will also deal with the important questions of ventilation and temperature. The present paper will be concerned with matters of construction only.

The subject may be conveniently divided as follows:—

1. General Design.
2. Motive Power.
3. Air-Compressors.
4. Boring Machines.
5. Removal of Spoil.
6. Cost.

1. General Design.

The tunnel forms a straight line in plan, Fig. 1, Plate 6, having a total length of 14,900 metres (about 9¼ miles) between the northern portal at Göschenen and the southern portal at Airolo. The former is at a height of 1,109 metres above the sea (about 3,640 feet), and the latter of 1,145 metres (about 3,760 feet). From the northern portal the line rises with a gradient of 0·5 per cent. (1 in 200), to a point 7,801 metres within the tunnel (about 4·9 miles), and then falls towards the southern portal with a gradient beginning at 0·05 per

cent., then changing to 0·2 per cent., and ending at 0·1 per cent. The trigonometrical and other methods by which the centre line of the tunnel was originally fixed, and adhered to during construction, will not here be entered upon.

It will be seen by Fig. 1 that the actual carriage pass of the St. Gothard lies considerably to the west of the tunnel, and at a much greater elevation, namely 2,114 metres (about 6,940 feet) above the sea. It was at first proposed to carry the railway over the plain of Andermatt, and for some distance further up the valley, and to pierce the main chain with a comparatively short tunnel not far from the pass. This tunnel could have been executed by means of shafts from above; but it was found that the plan would not have resulted in any true economy. The proposal belongs in fact to the period when there were still many who doubted the practicability of constructing tunnels of such a length as 9 miles. Even in 1859 M. Flachat, in his work "De la Traversée des Alpes," advised the giving up of the work already begun at Mont Cenis, and the substitution of a shorter tunnel at a higher level. He even maintained that all the Swiss passes might be crossed by summit railways, at a height of say 2000 to 2100 metres above the sea (6500 to 7000 ft.). But the conditions of climate forbid any such attempt. The snow lies for 3 to 4 months of the year at a height of 2300 feet, for 5 to 6 months at a height of 3300 ft., and for 8 or 9 months at a height of 6000 to 7000 ft. At the level of 2300 ft. it attains every winter a depth of over 3 ft.; at 3500 ft. a depth of 6 ft.; at 4500 ft. (*e.g.* at Bardonnecchia on the Mont Cenis line) an average depth of 11 ft.; and at 5000 ft. a depth of about 13 ft. In addition, the well-known effect of snow drifts has to be considered. At heights of 5000 to 6000 feet a storm will often drift the snow to a depth of 50 ft. or more. Such masses cannot be attacked by the snow plough, and can only be removed by hand labour; which obviously could not be obtained to an extent sufficient to keep clear an ordinary railway, especially as such drifts may occur at any point, and snow storms in such regions sometimes last for a week together.

The covering in of the railways by galleries, as practised on the Pacific line across the Rocky Mountains, would not solve the

difficulty; both on account of the much greater cost of construction in that case, and from the fact that the lifting of the trains to a higher level would largely and permanently increase the cost of haulage. In the case of the St. Gothard line, the only practical question was whether it should be continued over the plain of Andermatt to Hospenthal, at a height of about 4,800 ft. above the level of the sea. The tunnel would then have had a length of about 6½ miles, say 3 miles less than its length as made. But this shortening of the tunnel would not have outweighed the disadvantages due to its higher level, as indicated above. An intermediate position between Göschenen and Hospenthal would not have shortened the tunnel by any material amount. It cannot be doubted therefore that the line actually chosen was the best for the St. Gothard Railway, especially looking to its great importance with regard to the traffic of Central Europe. For lines of less consequence, and in more southern latitudes, a higher level might of course be advantageous.

The construction of the long tunnel having thus been decided on, and the actual trace laid out, a contract was entered into with Messrs. Favre and Co., of Geneva, for the completion of the work. In this contract it was provided that the tunnel should be completed within eight years. This time is much shorter than that occupied in the case of the Mont Cenis Tunnel; but that was blasted by gunpowder instead of dynamite, and the boring machines had also been much improved in the interval. As a matter of fact, the time occupied was about 9¼ years of continuous labour day and night, the work having been commenced in the summer of 1872, and completed towards the end of 1881.

It would have been possible to sink one shaft near Andermatt, at a distance of about 3½ kilometres (2·2 miles) from the northern portal. This shaft would have been about 300 metres deep (say 1000 feet). It is obvious that little would have been gained by this step, and the contractor never entertained the proposal.

The actual method of driving the tunnel is shown by the section Fig. 3, Plate 8, and is known as the Belgian method. A heading A (in German, *First-stollen*) was first driven at the top of the tunnel, 2·5 metres broad and 2·5 metres high (8·20 ft. square). Side widenings

B B were then made on either side of this heading, so as to complete the whole arch of the tunnel (*Calotte*), which was then lined with brickwork. A bottom cut (*Sohlenschlitz*) was then made in the floor, extending to the bottom of the tunnel, but lying almost wholly on one side of the centre line. This was made in two cuts, C and D, and when it was completed, an abutment (*Strosse*) was still left on each side, one of them much wider than the other. The narrower one E was then cleared out and the side wall put in, and finally the wider E_1 was also cleared away and the side wall put in, as shown by dotted lines; and a single line of rails was laid, the laying of the second line being reserved for some later period when a double line should be made necessary by the increase of the traffic. This however was so large, from the period of opening, that the second line is already being laid. A drain F is cut at the corner.

The rocks passed through in the tunnel have been described as follows by the official geologist, Dr. Stapff, taking them in order from the north end.

1. The "Finsteraarhorn Massiv," A B, Fig. 2, Plate 7, which is granitic gneiss, very hard and compact, and extends for about one-seventh of the distance.

2. The "Ursern Mulde," B C, which is gneiss, rich in mica, with intervening quartzose and greenish layers. There was some amount of water in this rock.

3. The "Gothard Massiv" of pure gneiss, C D, the beds intersecting the axis of the tunnel at a high angle, and occupying about one half the total length.

4. The "Tessin Mulde," D E, which is mica schist, occupying one-fifth of the length at the southern end. This rock varied much, and yielded a good deal of water.

The whole of the rock lay in beds nearly at right angles to the axis of the tunnel, and was favourable both for boring and blasting; except the granite, No. 1 above, and a length of about 400 yards of serpentine, situated about 5,300 yards from the north entrance: these proved very hard.

There was also, about 2,800 yards from the north entrance, a length of about 85 yards at F, Fig. 2, where the gneiss changed into

a species of china-clay. This became known, during the making of the tunnel, as the "pressure-length" (*Druck-partie*), and gave great trouble by collapsing. Unfortunately the critical nature of this clay was not at first recognised. It was worked by the Belgian method described above, driving the heading along the top; but in this compressible material it would have been better to adopt the German system, running the first heading along the bottom, and making good the walling on each side as the work proceeded. Instead of this, the arch at the top was first put in, and this, having no proper abutment or cross-tie, gradually spread at the springings and let down the crown. The first repairs attempted were not sufficiently systematic, and the length continued to move and collapse. It was finally made secure by walling of great thickness, and capable of resisting the extraordinary pressure.

2. Motive Power.

The motive power at both ends of the tunnel was furnished by the streams in the neighbourhood, but the conditions were by no means the same at the two ends. At Airolo the only available source at first was the Tremola torrent, from which the supply in the depth of winter sometimes fell to 200 cubic metres (7000 cub. ft.) per second. To obtain sufficient power it was necessary to lead the water from a vertical height of 181 metres (594 ft.). Such a head, applied to powers above 200 H.P., is very rare, and occasions great practical difficulties. Besides the tendency to leakage in the pipes under such a pressure, the high speed of the issuing water, and consequently of the revolving turbines, forms a serious evil; since any want of adjustment or inferior workmanship causes great unsteadiness and consequent wear and tear. The water at such speeds has an extraordinary effect on both cast and wrought iron, and even on steel, riddling them with a number of small holes, and rendering renewal necessary in a few months. This effect is supposed to be due to oxidation, stimulated by impact and by the air contained in the water. Subsequently, in 1874, a long channel

was constructed from the Bedretta Thal, so as to open a second source of supply.

At Göschenen the supply was taken from the Reuss with a head of 93 metres (305 ft.), and the minimum supply was from 1200 to 2000 cubic metres (42,000 to 70,000 cubic ft.) per second. The power thus obtained, amounting on the whole to 1500 H.P. at Göschenen and 1120 H.P. at Airolo, was made to actuate turbines driving high-speed air-compressors.

At Airolo the turbines, originally three in number, were supplied by Escher Wyss and Co., of Zurich, and are of the type called "tangent wheels" with vertical shafts. The diameter is 1·20 metre (3·94 ft.), thickness of metal 27·7 millimetres (1·09 in.), and speed 390 rev. per min., giving a tangential velocity at the outside of 24·5 metres (80·38 ft.) per second. The water is passed through a distributor with guide-blades, having five orifices, any of which can be closed by a curved slide-valve. The distributor and guide-blades are of bronze, which in these cases lasts five or six times as long as iron or steel. Behind the distributor is a stop-valve, composed of a principal valve having a second and smaller one in the centre of it. This smaller valve is opened first and closed last, and thus diminishes the shock occasioned by starting and stopping the water under so high a pressure. The pivot of the turbine rests on four discs of hard bronze and two of hardened steel, all polished. The surfaces in contact are one concave and the other convex.

At Göschenen the turbines were on the Girard system, constructed by B. Roy and Co., of Vevey. These have horizontal axes, and receive the water on a portion only of their circumference. The water passes through a distributor with eight orifices, regulated by a circular valve placed inside the revolving crown. The speed is 160 rev. per min., the outside diameter 2·4 metres (7·87 ft.), and the number of vanes 80. There were originally three of these turbines, each using 800 litres per second (28 cub. ft.), and each giving a net power of 250 H.P. In 1876 two similar turbines were added, each 5·05 metres outside diameter (16·56 ft.), and each using 480 litres (17 cub. ft.) per second, with a head of 73 metres (239 ft.), and giving a net

power at the shaft of 325 H.P., at 70 rev. per min. A similar pair were fixed at the same time at Airolo.

3. AIR-COMPRESSORS.

At Airolo three sets of air-compressors, three in a set, were erected in 1873, by the "Compagnie de Construction" of Geneva. These were of the Colladon type, and were made with interchangeable parts, in order to reduce the time of repair to a minimum.

The three sets of compressors and the three turbines were mounted in succession along the shop, Figs. 4 to 6, Plates 8 to 10, the compressors C lying horizontally, whilst the turbines T are vertical. Above each turbine is a horizontal shaft I, carrying a bevel wheel H, which gears into a bevel pinion on the vertical turbine-shaft, Fig. 5. At each end of this shaft I, and in line with it, is another horizontal shaft L, having three cranks at 120°, to which are attached connecting-rods from the three compressing cylinders C. These shafts L can be connected with the first shaft I by clutch-gear V, Fig. 4, so that one or both sets of compressors can be worked as desired.

The compressors, Fig. 6, Plate 10, are double-acting, and placed parallel to each other. The piston-rods N pass through both ends of the cylinders, and are worked by connecting-rods M from the three cranks. The diameter of the cylinders is 0·46 m. (18·11 in.), and the stroke of the piston 0·45 m. (17·72 in.), which at 390 revolutions per min. of the turbine gives a mean piston-speed of 1·35 m. per second (266 ft. per min.). The position of the cranks gives a uniform motion without the employment of a governor.

To cool the air during compression, two methods are adopted. In the first place the cylinder is provided with a jacket, in which there is a continual circulation of cold water. The piston-rod N is also made hollow, and carries within it a copper water-tube O, 0·04 metre diam. (1·57 in.). This tube, which is open at each end, has, near the middle, a collar Z outside it, of diameter equal to the bore of the rod, which it therefore closes. On each side of this collar the rod is pierced with three holes communicating with the interior of the piston, thus putting in communication the annular spaces within

the piston-rod N, on either side of the collar Z. A small fixed tube Q passes through a stuffing-box into the water-tube O. The cold water enters through the tube Q, returns from the other end outside the tube O, passes through the interior of the piston to get from one side to the other of the collar Z, and returns to the pipe Y, whence it is conducted away through a flexible hose. By this means the surfaces in contact with the compressed air, both inside and out, are kept always cool, whatever the speed; and if the air be dry, no other cooling arrangement is necessary.

Secondly, there are two spray injectors fixed at each end of the cylinder. The water for these is filtered first through a sand filter M, Fig. 4, Plate 9, and then through a wire sieve into a reservoir N. The object of this filtration is to get rid of the fine granite silt found in Alpine water, and so to prevent the wear of the packings, &c. The filtered water arrives at the compressors through the pipes P, passes through the air-vessels E, is compressed by a pump attached to the cross-head of the compressor, and is forced as fine spray into the cylinder. The volume of injected water is less than $\frac{1}{1000}$ part of the air used in the same period. It passes with the compressed air through the exhaust S, Fig. 6, and through the pipes R, to the large reservoirs shown in Fig. 4, Plate 9, where the water is deposited.

The compressors at Göschenen are similar in arrangement to those at Airolo, and have the same method of cooling the piston and cylinder. They were made by Messrs. B. Roy and Co., of Vevey. The turbines make 160 revs., and the driving-shaft 80 revs. per min.: the diameter of the cylinder is 0·42 metre (16·5 in.), and the stroke 0·65 (25·6 in.). Each set of three compressors will deliver 4 cb. m. (141 cub. ft.) per min., compressed to 8 atms. total. The piston packing is formed of two bronze rings, with a space between them, which is filled with water through a hole from the inside of the piston. This water forms a liquid packing, and at the same time cools the walls of the cylinder during the stroke. Some of it also escapes past the rings, and entering the cylinder takes the place of the spray in cooling the compressed air; for this purpose it is raised to a higher pressure when necessary by a special pump.

At each end of the tunnel two groups of compressors were

added in February 1875 to the three sets of compressors first laid down and described above; the power of the latter falling short of the requirements of the work. Finally, in the summer of 1876, still larger power being required, two further pairs of large compressors of improved construction were laid down in a fresh building.

4. Boring Machines.

Several different types of rock drill were employed more or less at the St. Gothard Tunnel. Amongst these may be mentioned the Ferroux, the Mackean and Seguin, the Dubois and François, the Turrettini, the Burleigh, &c. The Ferroux drill was the first to be employed, having been invented in 1873 specially to work in this tunnel. In 1875 the original was superseded by a simpler form devised by the inventor, and this improved drill did the greater part of the work from henceforward. As space will not allow of a description of all the varieties used, attention will be confined to this drill as the most successful example.

The improved Ferroux drill is shown in Figs. 7 and 8, Plate 11, with details enlarged in Figs. 9 to 12. It is about half the weight of the older form, and less expensive. L, Fig. 7, is the main feeding cylinder, in which works the piston M, fixed to a hollow piston-rod N. The outer end of this rod is connected to the larger or working cylinder T. In the latter, enlarged in Fig. 10, works the striking piston O, which is prolonged into the piston-rod Q, carrying at its further end the chisel or bit. The piston O is conical at each end. At either end of the cylinder T are sockets at right angles to it, and in these work the small plug-valves *aa*, which operate the entrance and exhaust of the air. These plugs are raised and lowered by the piston O, which as it reciprocates brings its conical ends under each of the plugs alternately, and so lifts it. The plug which is raised acts through the lever B to depress the other, and thus opens the other end of the cylinder to the outer air, whilst itself opening a passage from the compressed air in the chamber P to its own end of the cylinder. The piston is thus driven back to the other end, where the same operation recurs, and thus the reciprocation is carried on. The compressed air enters the feeding cylinder L, Fig. 9, from the

supply-pipe through the stop-cock I, and passes to the air-chest P, Fig. 10, through the interior of the hollow piston-rod N. At the same time, by pressing against the end of the piston M, Fig. 9, the air forces the rod N, with the working cylinder T attached to it, forwards towards the rock to be drilled. Along the top of the bearers A, Fig. 10, which carry the machine, is a rack R. When the hole has been deepened by a distance equal to the interval of the teeth of this rack, the conical shoulder C of the rod Q has advanced so far as to raise the fork D, which has two pawls engaging in the teeth of the rack. When these are raised clear of the rack, the striking cylinder T advances by the length of one tooth; and this goes on until the cylinder has advanced the whole length of the rack. A plug Z, having the compressed air below it, operates to keep the fork D down upon the rack, and to bring it down again the moment it is released by the piston-rod.

To prevent the striking cylinder from moving backwards in the opposite direction, a small cylinder X, Fig. 10, is provided at its rear end, and is open to the compressed air. In this cylinder is a plug, which presses upwards against a stirrup, carrying at its lower part the cross-piece H, Fig. 11. This cross-piece engages with two racks on the under side of the bearers A, and having their teeth in the opposite direction to that of the racks on the upper side. Whilst this piece H is engaged with the rack, no backward motion is possible; but it can be released at any time, to bring back the drill, by pushing down the stirrup.

The rotation of the rod Q, which carries the drill, is given by an inclined groove in the enlarged part of the rod. Into this groove, shown in section in Fig. 12, fits a projection *c* from the ratchet-wheel *d*. As the striking rod Q advances towards the rock, the groove in it compels the wheel *d* to turn in the direction of the teeth. When the rod comes back for another stroke, the wheel is prevented from returning by the pawl F, and therefore the piston-rod itself is compelled to turn.

To bring the machine back when the hole is finished, the cock I is closed and the cock J is opened, Fig. 9. The air then escapes from behind the piston M through the chamber P into the atmosphere, while it enters through the pipe K into the annular space on the

front side of the piston M, and pushes it, with the striking cylinder and piston, back to the rear end of the cylinder L.

The weight of the machine is about 180 kilograms, or 397 lbs., and the gross quantity of compressed air used per stroke is 1·40 litres (85 cub. in.). The advantages claimed for it are diminished weight and cost, reduction in the number of parts, ease of maintenance, and durability.

The drill is connected with the carriage by means of a pin passing through the plate Y, Figs. 7 and 8. This carriage, which weighs about 2,400 kilograms (2·4 tons), is shown in Figs. 13 to 15, Plates 12 to 14. It is so arranged that, in a heading only 2·60 metres wide (8½ ft.), the débris can be removed without shifting the carriage, as there is room for a small tramway, 0·30 metre gauge (11·8 in.), to be laid beside the carriage. The débris is filled into small trucks running on the tramway, and from these into the tipping wagons behind the carriage.

The carriage is arranged for six drills working together. These are placed three on each side, one above the other, the middle one being shown dotted in Fig. 13, Plate 12; and are mounted in sockets carried upon arms which can be moved by means of screws; the workmen standing at the side are able to manage these with facility. In order that the drills may be directed to any point in the face and at any angle, the sockets at the front end AA are made capable of sliding laterally along the arms BB, Figs. 14 and 15, so as to traverse inwards or outwards as required. The movement is given by screws S lying parallel to the arms. The arms are raised or lowered as a whole by means of the vertical screws C. The arms in rear DD, Figs. 13 and 14, can also be raised or lowered by the vertical screws T; and the sockets EE on the arms can swivel round them, so as to incline the drills at the required angle to the vertical.

5. Removal of Spoil.

The rock, after being blasted, was loaded into wagons, and hauled out of the tunnel by small locomotives worked by compressed air. At the face of the heading the rock was first loaded into small tip wagons, which were run back on the narrow-gauge tramway already described, past the drilling machines, and then

tipped into ballast wagons on a lower level. The locomotives, shown in Figs. 16 and 17, Plates 14 and 15, were built by Schneider & Co. of Creusot. The frames, springs, wheels, cylinders, cranks, reversing gear, &c., are all similar to ordinary locomotives. On the frame is mounted a cylindrical reservoir A containing the air under pressure. The pressure of course diminishes during the journey. From the reservoir the air passes through an automatic expander R, where it is expanded down to the cylinder pressure, which is always kept the same. Between the expander and the cylinders it passes through a small reservoir B, which acts as a heater, and at the same time prevents shocks to the valves when the engine is started or stopped. The pressure in the main reservoir A is limited only by the power of the air-compressors, and the tightness of the joints in the pipes. In practice it reached 14 atms. (206 lbs. per sq. in.). By a special arrangement the compressors could be supplied with air already compressed to 7 atms., at times when the efficiency would have been too low, if compressing direct to 14 atms.

The expander R, shown enlarged in Fig. 18, Plate 14, is composed of a vertical cylinder AA, communicating by a pipe Z with the main reservoir, and partly surrounded by a jacket B. This jacket is filled with the partially expanded air, which can pass into it through two series of holes, *aa* and *bb*. From the jacket it passes to the engine cylinders through the pipe Y. At the lower end of the cylinder, next to the holes *bb*, there is a solid cover; the upper end communicates with the atmosphere. Within the cylinder works a piston-rod H, carrying two pistons. Of these the upper one is of the ordinary form, but the lower is prolonged into a trunk, pierced with holes *ee*. The stroke is such that the bottom of the trunk never covers the holes *bb*; so that the bottom end of the cylinder below the trunk is always in communication with the jacket. The upper end of the piston-rod carries a plate K, and a spiral spring N holds this plate apart from another plate L, whose distance from the cylinder can be regulated by means of the screw M. This plate L being fixed, the spring tends to keep the trunk at the bottom of its stroke, and so to keep the holes *ee* opposite the holes *aa*, as shown in Fig. 18. If compressed air now enters through the pipe Z, it passes through these holes into the jacket B, and thence through the holes *bb* into the space beneath

the trunk, where, its pressure being greater than the atmosphere, it tends to push the trunk upwards against the pressure of the spring. If its pressure be greater than the total resistance, the trunk rises, the holes *ee* become blind with those *aa*, and the air ceases to pass into the jacket. Now suppose the pipe Y to be opened, so that the air in the jacket escapes to the engine. Then the upward pressure on the bottom of the trunk diminishes, the trunk descends, and the holes *ee* become partly open to those *aa*. The result of these two tendencies is that the area of the holes *ee* which is open to *aa* is kept of such magnitude as will cause the pressure of the air in the jacket to balance exactly the reaction of the spring. The trunk is thus kept in equilibrium, and the pressure at which the air passes to Y is kept constant. Its amount can be varied if necessary by screwing up the spring.

The heating apparatus is on the Mékarski system. The heater B, Figs. 16 and 17, Plates 14 and 15, holds 390 litres (13·77 cub. ft.), and is fitted with pipes and gauge-cocks for showing the water-level in the interior—glass gauge-tubes not being applicable on account of the severe shaking and shocks to which the engine is exposed. The heater and the pipes leading to it are clothed with wood and felt. The mixture of compressed air and water passes out of the main reservoir through a pipe P, furnished with a cock and passing to the bottom of the heater, where, in order to divide the air into thin jets, it terminates in a rose. These jets are heated by the hot water, and the air then rises to the top of the heater, whence it is conveyed to the expander R. From this it passes to a pipe S running between the main frames, and dividing into two branches, which lead to each of the working cylinders.

To charge the engine, the cock between the main reservoir A and the heater B is closed, and the inlet pipe of the heater is coupled to a pipe leading from a fixed boiler. There are two outlet pipes from this boiler, one in the steam space and one in the water space, so as to give steam or water as required. The lower is first coupled to the heater, which is then filled with water up to the required level. This pipe is then shut off and the heater coupled to the other, and filled with steam up to the desired pressure. During the same time the main reservoir A has been coupled to a pipe leading from the

compressed-air mains, and has thus been recharged with compressed air. When the charging is completed the inlets are closed, and the cock between the main reservoir and the heater is opened: the engine is then ready for working. The pressures are ascertained by three gauges, one on the main reservoir, one on the heater, and one on the pipe leading to the working cylinders.

The principal dimensions &c. of the engines are given below.

Capacity of the large reservoir . .	7·600 c.m.	268 c. ft.
Internal diam. of do. . .	1·700 m.	5·58 ft.
Length of do. . .	3·550 m.	11·64 ft.
Thickness of steel shell plate . .	0·015 m.	0·59 in.
Thickness of the dished ends. . .	0·017 m.	0·67 in.
Capacity of the heater	0·390 c.m.	13·77 c. ft.
Internal diam. of do.	0·800 m.	2·62 ft.
Length of do.	0·880 m.	2·89 ft.
Thickness of steel in do.	0·012 m.	0·47 in.
Diam. of cylinder	0·204 m.	8·03 in.
Stroke of cylinder	0·360 m.	14·17 in.
Diam. of tread of wheels	0·760 m.	2·49 ft.
Volume swept through by piston in each stroke	0·0117 c.m.	0·413 c. ft.
Volume swept through by both pistons per metre forward . .	0·0196 c.m.	0·692 c. ft.
Absolute initial pressure of compressed air in the principal reservoir	12 kg. per sq. cm.	171 lbs. per sq. in.
Constant absolute pressure on entering the cylinders	4 kg. per sq. cm.	57 lbs. per sq. in.
Extreme length of engine from buffer to buffer	5·000 m.	16·40 ft.
Weight of engine (about) . . .	7·400 tonnes.	7·4 tons.

6. COST.

The cost of the tunnel cannot be given with any great exactness, but the total cost may be taken as follows:—

(1)	Blasting of tunnel, making of water-courses, &c. .	41,700,000 francs.
(2)	Masonry, etc., inside the tunnel	13,300,000 „
(3)	Do. outside „	600,000 „
	Total	55,600,000 „

To this must be added the cost of various extra works, of the preliminary work of triangulation &c., of repairing of damages, of ballasting and laying the line, of materials, signals, telegraphs, &c., which together may be taken at 2,000,000 fr. This makes the total cost of the tunnel about 58,000,000 fr., or for a length of 14,890 metres 3900 francs per metre (£140 per yard), or in round numbers £250,000 per mile. With regard to special items, the cost of blasting was on the average about 46 fr. per cb. m. (28*s.* per cb. yd.). The cost of walling per cb. m. may be taken as follows:—

Wages	13	francs.
Hewing and transport of stone, and selection and transport of rubble for packing	48	„
Hydraulic mortar and cement	6	„
Centres, scaffolding, &c.	3	„
Superintendence, &c.	6	„
Total	76	„

(Say 46*s.* per cubic yard.)

This however is rather the contract price than the actual cost; the latter was much reduced by using the rock blasted on the spot to make the masonry. Again, for the greater part of the length this masonry was merely a lining put in for security, the rock being amply strong enough to stand without it.

General Conclusions.

In conclusion, the points connected with the construction of this tunnel, which seem particularly to call for notice and comment, may be stated as follows:—

(1) The advantage in such cases of constructing a long tunnel at a comparatively low level, instead of a shorter tunnel at a higher level.

(2) The proper position of the leading heading in the section, and the proper mode of completing the full section from it.

(3) The best construction and arrangement of the turbines and air-compressors, to utilise a comparatively small quantity of water at a very high pressure and velocity.

(4) The best construction and arrangement of the drilling machines.

(5) The best means of keeping a long heading cool, in view of the very great loss of efficiency which is found to result from too high a temperature.

It is only on the first two of these points that any remarks will be made on the present occasion.

With regard to the first of these points, the superior limit to the level at which such a tunnel should be made has been shown above to be fixed by considerations of climate. The inferior limit to its position is determined on the one hand by the length, as influencing the time and cost of construction, and on the other hand by the height of the overlying strata above the tunnel, as influencing the heat within the heading. From observations made at the St. Gothard and elsewhere we may assume that the limit of temperature at which men can work at all in a tunnel is 50° C. (122° F.) in dry air, and 40° C. (104° F.) in air saturated with moisture. The observations at Mont Cenis and the St. Gothard also go to fix the relation between the depth below the surface and the internal temperature. At the St. Gothard the average increase appeared to be 2° C. per 100 metres vertical height (or say 1·1° F. per 100 ft. vertical height). The form of the overlying mountain, and the nature of the rock, have of course also an influence on the temperature. The amount of water to be expected is a matter on which it is generally impossible to speak with any certainty; but a long tunnel will always be more or less wet. Many modes have been suggested for drying and cooling the air within the heading, but there is little to be said practically as to their efficiency. The air used for ventilation is found to have little influence in either direction. These considerations have a practical bearing, for example, on the proposed Simplon Tunnel, which is to be nearly 12 miles long and only 2300 ft. above the sea. In this case the temperature of the rock would be about 47° C. (116° F.) according to the rule given above, as determined for the St. Gothard by Dr. Stapff. If the tunnel were raised to a level of 2600 ft., with a length of 10 miles, the temperature would be about 40° C. (104° F.); while if it were raised to a level of 3600 ft. with a length of 7½ miles, the conditions would be about the same as in the St. Gothard Tunnel. It follows that the

longest of these projected tunnels could not be made in the same way as was practised at the St. Gothard, and some improved method would have to be sought for.

As to the second point, *i.e.* the actual mode of driving the tunnel, the results obtained at the St. Gothard are of great interest. In the improvement of the drilling machines, and the employment of dynamite, that tunnel had a great advantage over the Mont Cenis; and accordingly the progress of the first heading was much more rapid. On the other hand the completion of the tunnel lagged much further behind. At the Mont Cenis the tunnel was opened for traffic 9 months after the junction of the headings, whilst the interval was 22 months at the St. Gothard. There arises therefore a question how the improved rate of progress, which has been achieved for the heading, may be extended to the work of completion.

Whilst in the Mont Cenis tunnel the leading heading was driven along the bottom of the section, M. Favre adopted the opposite course at the St. Gothard, and drove the heading along the top. In 1874 this method was sharply criticised by Professor Rziha and others; and although the discussion led to no very definite result, the Arlberg tunnel is being driven by means of a bottom heading. These works have been two years in progress; the rate of advance in the heading is half as great again as at the St. Gothard, and the completed work follows as closely behind it as it did at the Mont Cenis. Herr Bridel, chief engineer of the St. Gothard Railway, and formerly a supporter of the Belgian or top-heading method, has written a report comparing the two methods (top heading and bottom heading) under the three following heads:—

1. Influence of each method on the rapid completion of lengths already pierced by the heading.

2. Influence on the power of keeping back the pressure of soft rock.

3. Influence on the cost of construction.

His results are as follows.

Completion of Tunnel.—With regard to the first head, it is very important, where drilling machines are used in the enlargement of the heading, to have as many points of attack as possible, so that the workmen may not be too much crowded together. With a bottom

heading this is attained by adopting what is called the English system, in which openings are commenced in the sides and roof of the heading at a number of different places, corresponding to the rate at which the heading itself advances. It is obvious that the spoil from the furthest of these openings can be carried past the others without difficulty; which would not be possible in the case of a top heading, where the opening would have to be made in the floor and not in the roof. The bottom heading was adopted at the Mont Cenis tunnel, and also at the Arlberg tunnel; and in the latter, in spite of the much more rapid advance of the heading, the completed tunnel on 31st July, 1882, was only 1090 yds. behind the face of the heading on the West side, and 750 yds. on the East side. The same system, with slight modifications, was adopted at the Laveno tunnel, 1·9 mile long. Here the junction of the headings took place 368 days after the commencement, giving an average advance for the two ends together of 8·15 metres (26·7 ft.) per day. In the last month the advance was 37·7 ft. per day. Top headings were here carried forward at the same time as the bottom headings, and their junction took place two months after that of the latter. Openings were made at short intervals from the one to the other, and the spoil from the top heading was thrown down through these into wagons below. The completion and walling of the section did not lag behind; and the tunnel was open for traffic 4½ months after the junction of the bottom headings, and only 16½ months from the commencement of the work.

On the other hand, in the case of the St. Gothard Tunnel, the whole length under construction in October 1877 (a time when the works were in an exceptionally regular condition) was 2750 metres (say 3000 yds.); which may be compared with 1260 yards in the case of the Arlberg tunnel. Even theoretically, the length under construction with the method adopted at the St. Gothard can never be less than 2600 yards. Assuming a maximum progress of 165 yds. per month, it follows that the tunnel cannot be completed until 15·8 months after the junction of the headings. As a matter of fact the actual interval was over 21 months. In the Arlberg tunnel on the other hand the completion may be expected to follow within 5 months from the junction of the headings.

On the whole it would seem that the method of driving a top heading is not the best for any tunnel where machine drills are used for the sake of rapid completion of the work.

Pressure of Rock.—Where the rock is of a gravelly nature, so that it exercises great pressure, but is not itself compressible, both theory and practice show that if the Belgian method be adopted, and the arch put in without abutments, a sinking and crushing in of the arch cannot be prevented. The same is yet more certain where the rock is of a clayey or plastic nature, as has been shown on the line from Foggia to Naples, and also in the "pressure length" of the St. Gothard tunnel. Here it was found in many places impossible to complete the arch at all on the Belgian method; it was absolutely necessary to begin with the abutments and invert. In wet earth the Belgian method is clearly quite inapplicable.

Herr Bridel has drawn the following conclusions on this subject:—

a. The Belgian method is not safe where there is great pressure, and especially where the rock is plastic.

b. Even where all possible precautions are taken, the work is extremely difficult, slow, and expensive, and the success always doubtful.

c. With a top heading, the English method of completing the tunnel is possible indeed, but exceedingly costly, difficult, and slow.

d. With a bottom heading, this method is capable of any amount of development, and renders possible a much more rapid advance.

e. In a long tunnel it is impossible to tell whether plastic strata, or others exercising great pressure, will be met with, through which it would be necessary to drive a bottom heading. But it is exceedingly difficult to pass from working by a top heading to working by a bottom heading.

All the above conclusions point to the superiority of the bottom-heading system.

Cost of Construction.—The experience gained on this head leads to the following conclusions, as drawn up by Herr Bridel:—

a. With forced working (*i.e.* where the progress is to be as rapid as possible), when the conditions as to ventilating and drying the tunnel are the same, the general cost of blasting is nearly the same whether the leading heading is at the top or at the bottom.

b. The drying and ample ventilation of the working places are however much more difficult with a top heading than with a bottom heading, so that the latter system is really superior in these respects.

c. The removal, loading, and transport of the spoil is done much more easily, quickly, and cheaply with the bottom heading than with the top heading.

d. The formation of drains, and the laying of roads and of air and water pipes, are extensive and costly works with a top heading, but are a small matter with a bottom heading.

It follows that, where rapid progress is necessary, the bottom-heading system is to be preferred to the other.

At the Arlberg tunnel the contract price at 3 to 4 kilometres from each portal (which is about the average distance at the St. Gothard), and where the walling is thinnest, is as follows:—

	Fr. per metre.
Bottom or leading heading	374
Top heading, following it	242
Completion, except masonry to drains	1430
Masonry to drains	57
Total	2103
Add $3\frac{1}{2}$ per cent. for extras	73
Add interest on cost of plant, &c., supplied by the railway company (taking this as the same as at the St. Gothard)	470
Grand Total	2646
	(say £96 per yard.)

On the other hand the contract price at the St. Gothard tunnel was as follows:—

	Fr. per metre.
Total except masonry	2800
Masonry, minimum thickness	830
Total	3630
	(say £132 per yard.)

There is thus a difference in favour of the Arlberg tunnel of 984 fr. per metre (£36 per yard). This difference is certainly more than can be accounted for by the somewhat harder character of the rock at the St. Gothard: and thus confirms the conclusion that, at least with forced working, the bottom-heading system is the cheaper of the two.

Abstract of Discussion.

The CHAIRMAN (GEORGE B. RENNIE, Esq.) said they would all agree with him that the paper was a most interesting one, and his only regret was that it was then too late to have a discussion upon it. Herr Wendelstein had come from Switzerland expressly to be present, and with the permission of the members would like to make a few remarks.

Herr WENDELSTEIN (speaking in French) said he very much regretted not being able to speak to the members of the Institution in their own language. He wished to express his thanks to the President for the confidence he had placed in him in requesting him to bring forward his paper; and to the Secretary for his valuable assistance in the preparation of the paper and the diagrams. The members present were no doubt well acquainted with the enormous mountain chain of the Alps, its torrents, its avalanches, and its glaciers; and he need not say the project of crossing such a chain of mountains by a railway must be a deeply interesting one. The entire subject of the construction of that railway, in all its details, was far too wide to be entered upon in a single paper. He had therefore dealt with the "great tunnel alone," but even that was too wide a subject to be considered in its entirety; and he had therefore confined himself to points of mechanical interest, reserving for a subsequent occasion certain physical and physiological questions, relating to ventilation, &c. The tunnel was at present the longest in the world; but he hoped that the example having been set at the St. Gothard, others would not be slow in following it. Indeed the Arlberg tunnel, which was being now rapidly pushed forward, had profited largely by the experience gained in the construction of the St. Gothard. The Simplon tunnel was at present under discussion, and he hoped that before long both would be exceeded by the Channel tunnel, which would be about double the length of the St. Gothard.

The CHAIRMAN said the author had asked permission to lay before the meeting the following letter from Herr Dapples, Chief Government Inspector of Swiss Railways:—

"BERNE, *January* 23, 1883.

"MY DEAR MR. WENDELSTEIN,

"Your paper on the St. Gothard tunnel I have read with much interest, and found it in general conformable to facts.

"After the experience now obtained in the three long Alpine tunnels, the majority of competent engineers will probably agree with your conclusion, that, where rapid progress is necessary, the bottom-heading system is to be preferred to the other.

"The main advantage of a bottom heading lies in the facility and security of rapid transport, such transport being the main factor in rapidity of work in general.

"The Belgian system of tunnel working has sometimes economical advantages in short tunnels, when there is plenty of time for carrying out the works.

"As to the failure of the first masonry at section 2800, it should perhaps be ascribed to the many faults committed by the contractor, more than to the Belgian method itself. Such crushing of masonry by heavy pressure may also occur when other tunnelling methods are employed, and has for instance already occurred in the Arlberg tunnel.

"As to the probable highest temperature during the works in the projected Simplon tunnel, which you assume would be about 47° C. (116° F.), I observe that those who have made an especial study of the matters concerning the Simplon railway give a probable maximum of temperature of 35° C. (95° F.) as resulting from their latest investigations.*

"Very faithfully yours,

"ERN. DAPPLES."

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* In reference to this letter Herr Wendelstein points out that the manner in which the use of the Belgian method had caused failure in the completion of section 2800 had been fully gone into in the paper itself. It was there stated that to the mistakes committed in the first treatment of the evil, together with the increased disturbance of the ground thereby occasioned, and the consequent difficulty in accomplishing the work, the failure must be unhesitatingly ascribed. What is further said as to this portion of the tunnel might apply to the whole up to a certain point. The increased expenditure of time and money

He had now to propose a hearty vote of thanks to Herr Wendelstein, not only for kindly preparing his paper, but for coming from Switzerland to be present at its reading. It was always a matter of satisfaction to the members to have the assistance of foreign engineers, who were willing not only to prepare papers, but to come personally amongst them, and give the results of their experience by word of mouth.

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was chiefly occasioned by the unfortunate choice of the Belgian system, as well as by the insufficient supply of many necessaries, especially with regard to ventilation, so that the power of the men employed was not properly developed.

As regards the projected Simplon tunnel, the paper referred only to the line running underneath the Monte Leone, which rises here to 3565 metres above the sea (10,700 ft.). The Commission, profiting by the experience obtained at the St. Gothard, now proposes to take a line several kilometres more to the north-east, and also winding considerably, so that the tunnel may lie under the bottom of the Cherasca valley. It will thus be 20 kilometres in direct length (12·4 miles). It is believed that by adopting this course a temperature not exceeding 35° C. will be encountered, in which it is assumed human labour will be quite possible. It is intended also eventually to sink at either end of the middle length of the tunnel, which will be from 8 to 9 kilometres long (5 to 5½ miles), ventilating shafts about 800 metres in depth (2600 ft.), for the purpose of maintaining a favourable temperature throughout. As far as can be judged, a higher temperature must be encountered in the Simplon tunnel than in the St. Gothard, where it never exceeded 30·75° C.; and this high temperature must also be continued for a longer distance, because of the greater length of the tunnel. Should the tunnel therefore be undertaken, the question of neutralising the injurious influences of the heat must be seriously faced; but this point will be discussed in a subsequent paper.

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1883.

The Spring Meeting of the Institution was held at the Institution of Civil Engineers, London, on Wednesday, 11th April, 1883, at Three o'clock, p.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The Minutes of the last Meeting were read, approved, and signed.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following candidates had been found to be duly elected:—

MEMBERS.

James Herbert Bartlett,	Toronto.
Augustus Lea Bricknell,	London.
George Cawley,	Manchester.
Rowland Childe,	Wakefield.
Frederick Grew,	St. Leonards-on-Sea.
John Holroyd,	Manchester.
Thomas Instone,	Birmingham.
William Robert Lake,	London.
Sutton Harvey Lowe,	Lincoln.
William Penn Mather,	Manchester.
Gamble North,	Iquique, Chile.
Walter Pitt,	Bath.
James Edward Platt,	Oldham.
Arthur Lewis Shackleford,	Birmingham.
John Bagnold Smith,	Chesterfield.
Joseph Walker Sutton,	Crewe.

William Henry Trentham, ...	London.
Charles Henry Turnbull, ...	Liverpool.
Arthur Wellesley Westmacott Willmott,	Antwerp.
Thomas Alured Wynne-Edwards, . . .	Denbigh.

ASSOCIATES.

Fung Yee, ...	London.
Henry Sandham, ...	London.

GRADUATES.

Henry Streatfeild Cotton, ...	London.
Robert Cumming, ...	London.
Joseph Whitworth Hulse, ...	Manchester.
Francis Watkins Keen, ...	Smethwick.
Bipradas Palchoudhuri, ...	Ipswich.
Henry John Spooner, ...	London.

The following papers were then read and discussed:—

On the Strength of Shafting when exposed both to Torsion and to End Thrust; by Professor A. G. Greenhill, of Woolwich.

On some modern systems of Cutting Metals; by Mr. W. Ford Smith, of Manchester.

At 5·30 p.m. the Meeting was adjourned to the following day. In the evening the Annual Dinner of the Institution was held at the Criterion Restaurant, Piccadilly.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 12th April, 1883, at Ten o'clock a.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The discussion upon Mr. W. Ford Smith's paper was resumed, and concluded.

The following paper was then read and discussed :—

On Improvements in the Manufacture of Coke; by Mr. John Jameson, of Newcastle-on-Tyne.

On the motion of the President, votes of thanks were unanimously accorded to the authors of the papers.

On the motion of the President, a vote of thanks was carried by acclamation to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of the Institution.

The Meeting then terminated.

ON THE STRENGTH OF SHAFTING WHEN EXPOSED BOTH TO TORSION AND TO END THRUST.

BY PROF. A. G. GREENHILL, OF WOOLWICH.

The object of the present paper is to bring before the attention of Mechanical Engineers some points arising out of the formula required in the design of Shafting, which is made to transmit at once a thrust and a twisting moment, as is the case with the screw-shaft of a steamer.

The writer has worked out a mathematical investigation (Appendix, p. 190), establishing for this case the following formula* :—

$$\frac{\pi^2}{l^2} = \frac{P}{EI} + \frac{T^2}{4E^2I^2}, \quad . \quad . \quad (1)$$

where the quantities involved are as follows:—

P = end thrust of shaft.

T = twisting moment of shaft.

I = moment of inertia of cross-section.

E = Young's modulus of elasticity.

l = maximum distance between bearings, which will allow a straight shaft to be stable.

The civil engineer, in the design of structures, has usually to deal with columns, subject only to thrust; and in that case the formula (1) becomes—

$$\frac{\pi^2}{l^2} = \frac{P}{EI} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

which is the well-known formula of Euler.

* This formula will be found on p. 74 of the 4th edition of "Machine Design" by Professor W. C. Unwin, to whom the writer had the honour of communicating it. He is not aware of its having been given previously, though such may have been the case.

But the mechanical engineer, in designing shafting, has to make the shafting sufficiently stiff to transmit some twisting couple T, and in that case, if there is no end thrust, the formula (1) becomes simply—

$$\frac{\pi}{l} = \frac{T}{2EI} \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Lastly, as mentioned above, there are cases, such as that of a screw-shaft, where a thrust P and a couple T are both to be transmitted; and the general formula (1) must then be employed.

In this formula it is assumed, as is usual in practice, that the angular velocity is sufficiently small for the effect of centrifugal whirling to be neglected; although in the mathematical investigation the writer has shown how this centrifugal whirling may be taken into account if necessary.

As a practical application of formula (1), take the case of the Cunard s.s. "Servia," of which the following details have been extracted from a description in "Engineering."

The I.H.P. is 10350, with 53 revolutions per minute.

The propeller shafting is of wrought iron, 164 feet long in 8 lengths, and 22½ inches in diameter.

The pitch of the screw is 35 ft. 6 in.

Supposing there were no slip, this would give, at 53 rev. per min. a speed of nearly 19 knots an hour; but the actual speed measured was 17·85 knots.

Measuring, as in Unwin's "Machine Design," dimensions in inches, and forces in pounds, and assuming the whole of the power to be utilised by the propeller, we find that in the propeller shaft we have for the mean thrust—

$$P = \frac{10{,}350 \times 33{,}000 \times 12}{53 \times 35\frac{1}{2} \times 12} = 181{,}530 \text{ lbs.};$$

and for the mean twisting moment—

$$T = \frac{P \times 35\frac{1}{2} \times 12}{2\pi} = 213\frac{P}{\pi} = 12{,}307{,}000 \text{ inch-lbs.}$$

This mean value of T must be multiplied by the factor 1·77 in the case of a three-cylindered engine ("Machine Design," p. 192) to

obtain the maximum value of T, which maximum will therefore be given by T = 21,785,000 inch-lbs.

Also d = diameter of shaft in inches = 22·5; thence

$$I = \frac{1}{4}\pi d^2 \times \frac{1}{16} d^2 = \frac{\pi}{64}(22\cdot5)^4 = 12{,}581; \text{ and } E = 29{,}000{,}000,$$

for wrought iron.

Substituting these values in formula (1), we shall find

$$l = 4452 \text{ in.} = 371 \text{ ft.}$$

Now, in the figure representing a longitudinal section of the vessel, as given in "Engineering," the distance between the thrust-block and the stern-post bearing is about 120 ft.; and in this length the shaft is supported by no less than five bearings.

According to the above theory however, the shaft between the thrust-block and the stern-post bearing would have ample stiffness against the thrust P and the twisting moment T, without these intermediate bearings.

The practical suggestion to be deduced from the above theoretical considerations is therefore that, so far as stability of stiffness is concerned, these intermediate bearings might be suppressed; which would allow a greater amount of elastic yielding in the shaft, under the action of strains in the hull, and of other causes, and would thereby diminish the risk of its fracture.

It may however be found necessary to support the shaft between the thrust-block and stern-post against the bending effects due to gravity, and to the rolling of the ship; but it is suggested that this might be done by taking the weight of the shaft upon mere level supports, allowing side-play; or if this arrangement should be found to make the shaft roll out of line and to be difficult to lubricate—as suggested to the writer by Mr. W. J. Clark, of Southwick Engine Works, Sunderland,—then the weight of the shaft at intermediate points might be taken by means of revolving endless chains, passing over pulleys above, and thus allowing lateral deviation. Another plan, which has been suggested to the author, would be to have india-rubber cushions on each side of the bearing, between it and the plummer block.

At all events, neglecting the bending effects of gravity and the rolling of the ship, the screw shaft of any steamer ought to possess ample stiffness with bearings only at the thrust-block and the stern-post.

In further illustration of this subject the writer draws attention to the drawing, Fig. 1, Plate 16, of the s.s. "Dorset," kindly supplied by Mr. W. J. Clark.

From diagrams supplied at the same time, the maximum twisting moment of the engine, which we have denoted by T, appears to be 1,981,583 inch-lbs. Mr. Clark assumes that of the I.H.P., in this case 1683, only 42 per cent. is utilised in propelling the ship.* The

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* On this subject the following note has been received from Mr. W. J. Clark:—

It would be a more correct way of putting it to say that only 42 per cent. is utilised in *thrust;* for under the most favourable circumstances, considerably less than 42 per cent. of the I.H.P. appears to be utilised in overcoming the net resistance of the vessel. The subject of this loss of power was treated by the late Mr. William Froude, F.R.S., in his paper on the "Ratio of Indicated to Effective Horse-Power" read before the Institution of Naval Architects in 1876 (Transactions, p. 167).

Let E.H.P. = horse-power due to net resistance of vessel.

" A.H.P. = " " augmented resistance of vessel.

" I.H.P. = indicated horse-power.

Then Mr. Froude showed that

$$\text{I.H.P.} = 2 \cdot 7 \text{ E.H.P.}$$

$$\text{or E.H.P.} = \frac{37\tfrac{1}{2}}{100} \text{ I.H.P.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{and A.H.P.} = \frac{40}{100} \text{ E.H.P.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

or rather that A.H.P. varies from 40 to 50 per cent. of E.H.P. In the investigation the engines were working at their maximum power and speed—an important consideration.

There were circumstances in the case of the "Dorset" which lead me to reduce somewhat the estimate of the efficiency of her engines. The particulars which I supplied were meant to illustrate general practice, and the power was that of her regular work, and by no means the maximum power which could be obtained. The loss of efficiency due to the dead-weight friction is therefore considerably greater than at the maximum speed. In order to meet the varying conditions of draught, the propeller also was of rather a large area, and no doubt

pitch of the propeller being 20·5 feet, this would make the mean thrust on the shaft, which we have denoted by P, to be 17,787 lbs.

Taking however the maximum value of P, corresponding to the above maximum value of T, with a pitch of 20·5 feet, we have—

$$P \times 20{\cdot}5 \times 12 = T \times 2\pi.$$
$$\text{or } P = 50,613 \text{ lbs.}$$

With the same notation as before—

$$E = 29{,}000{,}000$$

$$I = \frac{1}{4}\pi d^2 \times \frac{1}{16} d^2,$$

$$d = 13{\cdot}375 \text{ in.}$$

With these data we have—

$$1{,}000{,}000 \times \frac{P}{EI} = 0{\cdot}88252$$

$$1{,}000{,}000 \times \frac{T^2}{4E^2I^2} = 0{\cdot}00029847;$$

So that— $$1{,}000{,}000 \times \left(\frac{P}{EI} + \frac{T^2}{4E^2I^2}\right) = 0{\cdot}88281847.$$

We here see how small $\frac{T^2}{4E^2I^2}$ is compared with $\frac{P}{EI}$, so that it may almost be neglected, and formula (2) employed instead of formula (1).

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the loss of power due to the friction of water and to the displacement by the blades (both very difficult to arrive at) would be greater than in the case under investigation by Mr. Froude. For these reasons, instead of 37½ per cent. I do not suppose that in round numbers more than 30 per cent. of the I.H.P. would be likely to be utilised in overcoming her net resistance. We should have therefore for this ship—

$$\text{E.H.P.} = \frac{30}{100}\text{ I.H.P.}$$

$$\text{A.H.P.} = \frac{40}{100}\text{ E.H.P.} = \frac{12}{100}\text{ I.H.P.}$$

Now the total thrust is equal to the sum of the thrust due to the net resistance and that due to the augmented resistance. Hence the power due to the total thrust is

$$\frac{30}{100}\text{ I.H.P.} + \frac{12}{100}\text{ I.H.P.} = \frac{42}{100}\text{ I.H.P.}$$

If l denote the length of shaft between bearings, then from the formula

$$\frac{\pi^2}{l^2} = \frac{P}{EI} + \frac{T^2}{4E^2I^2}$$

we shall find $l = 3343 \cdot 6$ in. $= 278 \cdot 5$ feet.

Except therefore for the purpose of supporting the weight of the shaft, the intermediate bearings, numbered 2, 3, 4, 5, 6, are not required, the stiffness of the shaft being ample without them.

A few words may be added on the important question of hollow shafts, as now frequently adopted for large vessels.

In comparing the stiffness of solid and hollow shafting, the only quantity affected is I, the moment of inertia of the cross-section; and the ratio of stiffness of two shafts may be taken to be the ratio of the values of I.

Thus, if a shaft have a hole bored through it, of diameter $\frac{1}{n}$th of that of the shaft, then the new value of I is $\left(1 - \frac{1}{n^4}\right)$ of the value for the solid shaft, while the fraction $\frac{1}{n^2}$ of the material has been taken away.

For instance, if the diameter of the hole is $\frac{1}{2}$ that of the shaft, then the stiffness is reduced only about 6 per cent. (*i.e.* $\frac{1}{16}$th) by a removal of 25 per cent. of material.

Again, for two shafts of the same weight, one solid, the other hollow, the hole being $\frac{1}{n}$th of the external diameter, the stiffness of the latter is to that of the former in the ratio of $\frac{n^2+1}{n^2-1}$; and if $n = 2$ as before, this ratio is $\frac{5}{3}$, showing a gain of 66 per cent. in stiffness in the hollow shaft.

It may however be objected that a crack in the hollow shaft will have much more serious effect than in the solid shaft; and this point therefore requires consideration.

In calculating the effect of a crack in the shaft on the value of I, we may consider separately the effect of a longitudinal crack and a transverse crack.

A longitudinal crack extending in a diametral plane right through the shaft will make the stiffness drop to one-third or one-

fifth of its original value, according as the shaft is solid or hollow; for the value of I must now be taken to be the sum of the moments of inertia of the two halves of the cross-section, taken about axes drawn through the centres of gravity of the two halves parallel to the plane of the crack.

Secondly, for a transverse crack, like a cross cut, extending inwards to a certain fraction of the radius, the new value of I must be taken as the least moment of inertia of the remaining cross-section. In this way the diminution of stiffness due to a crack of any assigned depth may easily be calculated.

A transverse crack however, once made, has a tendency to extend itself, because the fibres in the neighbourhood of the crack are the most strained, and it may thus gradually lead to the shaft being completely disabled. A longitudinal crack, on the other hand, may extend right through the shaft, and still leave it serviceable under a reduced strain.

To apply these principles to actual practice, take the case of the shaft of the steam-ship "City of Rome," which is composed of a hollow cylinder of external diameter 25 inches, and internal diameter 14 inches.

Therefore
$$\begin{aligned} I &= \frac{\pi}{64}\left\{(25)^4 - (14)^4\right\} \\ &= \frac{\pi}{64} \times 352209 \\ &= 17287; \end{aligned}$$

and the ratio of this value of I to what it would be for a solid shaft of the same external diameter is $1 - \left(\frac{14}{25}\right)^4$, or $0\cdot9$ nearly. On the other hand the weight of the solid shaft, compared to the hollow one, would be in the ratio $\frac{25^2}{25^2 - 14^2} = 1\cdot45$.

Again, the diameter of a solid shaft of the same weight would be $\sqrt{25^2 - 14^2} = \sqrt{429} = 20\cdot7$ inches; and the value of I for the hollow shaft, compared to the solid shaft of the same weight, will be—

$$\frac{25^2 + 14^2}{25^2 - 14^2} = \frac{821}{429} = 1\cdot9.$$

It may be urged, as mentioned above, that, granting these results while the two shafts remain perfect, yet a crack will have a much more serious effect in the hollow shaft than in the solid. Let us therefore consider the effect of a transverse crack, reaching to a depth of one inch, along the line A B, Fig. 2, Plate 16.

The determination of the value of I for the remaining sound cross-section of the shaft, about an axis through its centre of gravity parallel to A B, is rather complicated, and need not be given in full; but the new value is approximately I = 16,328, while for the sound shaft the value of I was found to be 17,287; so that there is a loss of nearly 6 per cent. of stiffness in the shaft in consequence of the crack. This loss of stiffness will increase very rapidly, with an increasing depth of the crack. On the other hand, the value of I, in the case of a solid shaft of the same diameter, will be diminished from 19,200 to 18,240, or by about 5 per cent. Thus, even in this particular, there is only an advantage of about 1 per cent. on the side of the solid shaft, as against all the various disadvantages which have been mentioned above.

It is with much diffidence that the author, as a mere theorist, ventures to bring these calculations and suggestions before the Institution of Mechanical Engineers, not being acquainted with the practical difficulties to be surmounted, in order to make the best design for shafting, and to diminish to the utmost the risk of fracture.

APPENDIX.

THEORETICAL INVESTIGATION OF THE STABILITY OF SHAFTING UNDER GIVEN FORCES.

1. *Euler's Theory of the Stability and Flexure of Long Columns or Shafts.*

The simplest way of approaching this subject is to take a straight cylindrical shaft of such length that, without straining it beyond the elastic limit, the shaft may be bent round until its ends may be joined together; the shaft will then, if uniform, spring into the form of a complete circular ring, as in Fig. 3, Plate 17 (*Vide* Unwin's Machine Design, 4th ed., p. 4.) The fibres of the shaft, which were originally straight and parallel to the axis of the shaft, will now become coaxial circles: their centres lying in the axis of the ring (*i.e.* a perpendicular through C to the plane of the paper), and their planes being perpendicular to this axis.

It is assumed in Euler's theory that, whatever be the extension or compression of the fibres of the shaft, there is no lateral contraction or expansion of the fibres—an assumption contrary to the strict laws of elasticity, but sufficiently near the truth for practical purposes. Consequently, on this assumption, if Fig. 4, Plate 17, represent a cross-section of the shaft when straight and unstrained, the same figure will represent the cross-section of the shaft, when bent into a circular ring, made by any plane containing the axis of the ring. Draw two rectangular axes Ox and Oy, through O the centre of gravity of the cross-section, respectively parallel and perpendicular to the axis of the ring.

Let A denote the area of the cross-section in square inches; and let dA denote the cross-section of a fibre of the shaft at any point P, whose ordinate is denoted by y.

Then if ρ denote the radius in inches of the circle made by the central fibre through O, the radius of the fibre through P will be $\rho + y$.

Since the resultant stress across the cross-section must reduce to a couple, the central fibre and all the fibres along Ox must be unstrained, while the fibres beyond Ox must be extended, and the fibres within compressed.

Assuming Hooke's law namely, that

$$\frac{\text{Tension}}{\text{Extension}} = \frac{\text{Pressure}}{\text{Compression}} = \text{modulus of elasticity E},$$

it follows that the tension of the fibre at P is $E\,\frac{y}{\rho}$, in lbs. per square inch; E being given in lbs. per square inch.

The resultant tension across the section A will therefore be $\Sigma\,E\frac{y\,d\,A}{\rho} = \frac{E}{\rho}\int y\,d\,A = 0$, as stated above; and the resultant couple due to the tensions and pressures of the fibres will be, taking moments about Ox,

$$\Sigma\,E\frac{y^2\,d\,A}{\rho} = \frac{E}{\rho}\int y^2\,d\,A = \frac{E\,A\,k^2}{\rho},$$

k denoting the radius of gyration of the cross-section about Ox. $E\,A\,k^2$ is called the flexural rigidity or stiffness of the shaft, and is denoted by L; and then two opposing couples, each of magnitude G, properly applied to the ends of a straight shaft of flexural rigidity L, will bend the shaft so that the central fibre becomes the arc of a circle of radius $\frac{L}{G}$.

2. *Modification of the Theory when the Shaft has a Thrust on it.*

The required modification may be derived from the preceding case of no thrust, by isolating the fibres forming a solid ring, the cross-section of which lies in the part of the original cross-section below Ox, Fig. 4, Plate 17.

Calling this new cross-section A_1, every fibre in the section A_1 is in a state of pressure, which varies as the distances from Ox; and if Q in Fig. 5 denote the centre of gravity of the section A_1, the resultant thrust P across A_1 will be given by

$$\begin{aligned} P &= \Sigma\,E\frac{y_1\,dA_1}{\rho} \\ &= \frac{E}{\rho}\int y_1\,dA_1 = \frac{E\,A_1}{\rho}\,O\,Q; \end{aligned}$$

and the resultant thrust will act through the point N, which is such that

$$O N = \frac{\int y_1^2 \, d A_1}{\int y_1 \, d A_1} = \frac{O Q^2 + k_1^2}{O Q}$$

$$= O Q + \frac{k_1^2}{O Q},$$

or $$O Q \times Q N = k_1^2,$$

k_1 denoting the radius of gyration of the area A_1 about the line through Q parallel to Ox.

If C be the centre of curvature of the fibres on Oy, then

$$P = E A_1 \frac{O Q}{O C}$$

or $$\frac{O C}{O Q} = \frac{E A_1}{P} = \frac{E}{p}$$

if p denote the mean pressure in lbs. per sq. in. in the section A_1;

Therefore $$\frac{Q C}{O Q} = \frac{E}{p} - 1;$$

and $$O Q \times Q N = k_1^2$$

therefore $$Q C \times Q N = \left(\frac{E}{p} - 1\right) k_1^2. \quad . \quad . \text{(A)}.$$

Representing the resultant stress across the section A_1 by the thrust P, applied at Q the centre of gravity of A_1, and by a couple G, then

$$G = P \times Q N$$

$$= E A_1 \frac{O Q \times Q N}{O C}$$

$$= \frac{E A_1 k_1^2}{O C}$$

$$= \frac{E A_1 k_1^2}{Q C}\left(1 - \frac{p}{E}\right).$$

Thus the flexural rigidity of the shaft, of cross-section A_1, is $E A_1 k_1^2 \left(1 - \frac{p}{E}\right)$, where p is the mean pressure in lbs. per sq. in. in the shaft.

The flexural rigidity or stiffness is therefore $1 - \frac{p}{E}$ of what it would be if there were no thrust.

3. *Application of the preceding Theory to the determination of the Greatest Thrust, consistent with Stability, that a Straight Shaft can sustain.*

Let C N Q, Fig. 6, Plate 17, represent the side view of the section of the shaft in Fig. 5, made by a plane perpendicular to the line of thrust O P N; and let A Q B D represent the curve assumed by the central fibre of the shaft when very slightly deflected from a straight line under the influence of the thrust P. Then C N Q may be taken as perpendicular to O N, and from the preceding article, equation (A),

$$\mathrm{QC} \times \mathrm{QN} = \left(\frac{\mathrm{E}}{p} - 1\right)k^2,$$

k now denoting the radius of gyration of the cross-section about a line through Q, perpendicular to the plane of flexure.

If in Fig. 6 we denote O N by x and N Q by y, then, to the order of approximation employed,

$$\frac{1}{\mathrm{QC}} = -\frac{d^2 y}{d x^2},$$

therefore $$\frac{d^2 y}{dx^2} = -\frac{y}{\left(\frac{\mathrm{E}}{p} - 1\right)k^2},$$

and $$y = a \cos \pi \frac{x}{l},$$

where $$\frac{l^2}{\pi^2} = \left(\frac{\mathrm{E}}{p} - 1\right)k^2.$$

The origin O is here taken where the deflection O A from the line of thrust, denoted by a, is greatest.

Fig. 6 is drawn for the case where the shaft has flat ends, which are allowed free side-play, and then l will denote the length of the shaft under the thrust P, or a pressure of p lb. per sq. in.

Also $\mathrm{P} = \mathrm{A}p$, if A denote the sectional area of the shaft in square inches.

If however l denote the length of the shaft before the thrust P is applied, and l_1 the length after the thrust P is applied, then

$$\frac{l_1}{l} = 1 - \frac{p}{\mathrm{E}}$$

$$\text{and} \qquad \frac{l_1^2}{\pi^2} = \left(\frac{E}{p} - 1\right)k^2,$$

$$\text{so that} \qquad \frac{\pi^2}{l^2} = \frac{p}{Ek^2}\left(1 - \frac{p}{E}\right)$$

$$= \frac{P}{E\,A\,k^2}\left(1 - \frac{p}{E}\right).$$

This differs from the usual formula in having the factor $1 - \frac{p}{E}$; but since $\frac{p}{E}$ is always small in practice, the ordinary formula

$$\frac{\pi^2}{l^2} = \frac{P}{E\,A\,k^2},$$

$$\text{whence } P = \pi^2 E\,A\frac{k^2}{l^2}, \text{ or } l = \pi k\sqrt{\left(\frac{E\,A}{P}\right)},$$

is sufficiently accurate for practical purposes.

The other cases that can arise are represented in Figs. 7, 8, 9, Plates 17 and 18. In Fig. 7 the ends of the shaft are supposed rounded, and then O will be the middle point of the shaft, and l the length without the rounded ends. In Fig. 8 one end of the shaft is flat and the other end rounded; and then $\frac{1}{2}\,l$ will denote the length of the shaft without the rounded end. In Fig. 9, Plate 18, both ends of the shaft must be supposed *encastrés*, and then $2l$ will denote the length of the shaft.

The preceding results are of course well known, and the discussion of them is to be found in all the text books on Applied Mechanics; the only novelty lies in the method of treatment, and the discussion of the assumptions employed.

4. *On the Stability of a Rotating Shaft, subject to Thrust and Twisting; for instance a Screw Shaft.*

Consider now a cylindrical shaft of sectional area A square inches, and d inches in diameter; of density equal to W pounds per cubic inch, and of flexural rigidity $L = E\,A\,k^2$. Suppose it to rotate with angular velocity ω between bearings l inches apart, and to be subject to a thrust P and a twisting couple T.

The straight form of the shaft will become unstable, and the central line of the shaft will become slightly displaced into a spiral

form under the combined action of the thrust P, the twisting couple T, and also the centrifugal whirling due to the angular velocity ω, provided a certain relation subsists between these quantities, P, T, ω, &c. It is required to determine this relation.

Refer the system to three rectangular axes Ox, Oy, Oz, and suppose that the central line of the shaft when straight coincides with the axis Ox.

Then at any point Q $(x\,y\,z)$ of the central line of the shaft, supposed to be slightly displaced into a spiral form, the impressed stress on the part of the shaft reaching up to $(x\,y\,z)$, from any point $(x_0\,y_0\,z_0)$, may be resolved into—

(i) A thrust P parallel to the axis of x, the shearing stress being neglected as an infinitesimal of the second order.

(ii) A couple of magnitude T having components about the axes,

$$-\mathrm{T}\frac{dx}{ds},\quad -\mathrm{T}\frac{dy}{ds},\quad -\mathrm{T}\frac{dz}{ds},$$

the thrust P and couple T being supposed to be due to a right-handed screw.

(iii) A couple due to the resilience of the shaft, being of magnitude $\frac{\mathrm{L}}{\rho}$, where ρ is the radius of absolute curvature of the central line, the axis of the couple in the binormal of the curve.

The direction cosines of the binormal are—

$$\rho\left(\frac{dy}{ds}\frac{d^2z}{ds^2}-\frac{dz}{ds}\frac{d^2y}{ds^2}\right)$$

$$\rho\left(\frac{dz}{ds}\frac{d^2x}{ds^2}-\frac{dx}{ds}\frac{d^2z}{ds^2}\right)$$

$$\rho\left(\frac{dx}{ds}\frac{d^2y}{ds^2}-\frac{dy}{ds}\frac{d^2x}{ds^2}\right)$$

The components of this couple of resilience, arising from the bending of the shaft, will be—

$$\mathrm{L}\left(\frac{dy}{ds}\frac{d^2z}{ds^2}-\frac{dz}{ds}\frac{d^2y}{ds^2}\right)$$

$$\mathrm{L}\left(\frac{dz}{ds}\frac{d^2x}{ds^2}-\frac{dx}{ds}\frac{d^2z}{ds^2}\right)$$

$$\mathrm{L}\left(\frac{dx}{ds}\frac{d^2y}{ds^2}-\frac{dy}{ds}\frac{d^2x}{ds^2}\right)$$

In consequence of the whirling motion of the shaft, there will also be a distributed force along the central line, having components of intensity in lbs. per unit of length

$$0, \quad \frac{m\,\omega^2}{g} y, \quad \frac{m\,\omega^2}{g} z;$$

where $m = \mathrm{A\,W}$, the weight of the shaft per inch in lbs.

It should be observed that with our units of an inch and a second $g = 32 \cdot 2 \times 12 = 386 \cdot 4$ about.

The conditions of equilibrium of any part of the shaft, reaching from any point $(x_0\, y_0\, z_0)$ to any point $(x\, y\, z)$, require therefore, taking moments about the straight lines through $(x\, y\, z)$ parallel to the axes of y and z, that the following equations hold for the component moments of resilience:—

$$\begin{aligned} &\mathrm{L}\left(\frac{dz}{ds}\frac{d^2x}{ds^2} - \frac{dx}{ds}\frac{d^2z}{ds^2}\right) - \mathrm{T}\frac{dy}{ds} \\ = \;&\mathrm{L}\left(\frac{dz}{ds}\frac{d^2x}{ds^2} - \frac{dx}{ds}\frac{d^2z}{ds^2}\right)_0 - \mathrm{T}\left(\frac{dy}{ds}\right)_0 \\ + \;&\mathrm{P}\,(z - z_0) - \frac{m\,\omega^2}{g}\int_{s_0}^{s}(x - x_1)\,z_1\,ds_1, \quad . \quad . \quad . \quad (1) \end{aligned}$$

and

$$\begin{aligned} &\mathrm{L}\left(\frac{dx}{ds}\frac{d^2y}{ds^2} - \frac{dy}{ds}\frac{d^2x}{ds^2}\right) - \mathrm{T}\frac{dz}{ds} \\ = \;&\mathrm{L}\left(\frac{dx}{ds}\frac{d^2y}{ds^2} - \frac{dy}{ds}\frac{d^2x}{ds^2}\right)_0 - \mathrm{T}\left(\frac{dz}{ds}\right)_0 \\ - \;&\mathrm{P}\,(y - y_0) + \frac{m\,\omega^2}{g}\int_{s_0}^{s}(x - x_1)\,y_1\,ds_1 \quad . \quad . \quad . \quad (2) \end{aligned}$$

These equations may be written

$$\begin{aligned} &\mathrm{L}\left(\frac{dz}{ds}\frac{d^2x}{ds^2} - \frac{dx}{ds}\frac{d^2z}{ds^2}\right) - \mathrm{T}\frac{dy}{ds} - \mathrm{P}z \\ &+ \frac{m\omega^2}{g}\int_{0}^{s}(x - x_1)\,z_1\,ds_1 = \text{const.} \quad . \quad . \quad . \quad . \quad (3) \end{aligned}$$

$$\begin{aligned} &\mathrm{L}\left(\frac{dx}{ds}\frac{d^2z}{ds^2} - \frac{dz}{ds}\frac{d^2x}{ds^2}\right) - \mathrm{T}\frac{dz}{ds} + \mathrm{P}y \\ &- \frac{m\omega^2}{g}\int_{0}^{s}(x - x_1)\,y_1\,ds_1 = \text{const.} \quad . \quad . \quad . \quad . \quad (4) \end{aligned}$$

On the supposition that the displacement of the central line is very small, we may put, in these equations:—

$$x = s,\ \frac{dx}{ds} = 1,\ \frac{dy}{ds} = \frac{dy}{dx},\ \frac{dz}{ds} = \frac{dz}{dx},$$
$$\frac{d^2x}{ds^2} = 0,\ \frac{d^2y}{ds^2} = \frac{d^2y}{dx^2},\ \frac{d^2z}{ds^2} = \frac{d^2z}{dx^2}.$$

Then the equations (3) and (4) become

$$L\frac{d^2z}{dx^2} + T\frac{dy}{dx} + Pz - \frac{m\omega^2}{g}\int_0^x (x - x_1)\, z_1\, dx_1 = \text{const.} \quad (5)$$

$$L\frac{d^2y}{dx^2} - T\frac{dz}{dx} + Py - \frac{m\omega^2}{g}\int_0^x (x - x_1)\, y_1\, dx_1 = \text{const.} \quad (6)$$

If the rotation ω be taken into account, these equations may be reduced to simultaneous linear differential equations; for differentiating with respect to x, and considering T constant, the displacement being small,

$$L\frac{d^3z}{dx^3} + T\frac{d^2y}{dx^2} + P\frac{dz}{dx} - \frac{m\omega^2}{g}\int_0^x z_1\, dx_1 = 0 \quad . \quad . \quad . \quad (7)$$

$$L\frac{d^3y}{dx^3} - T\frac{d^2z}{dx^2} + P\frac{dy}{dx} - \frac{m\omega^2}{g}\int_0^x y_1\, dx_1 = 0 \quad . \quad . \quad . \quad (8)$$

and differentiating again

$$L\frac{d^4z}{dx^4} + T\frac{d^3y}{dx^3} + P\frac{d^2z}{dx^2} - \frac{m\omega^2}{g}z = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$L\frac{d^4y}{dx^4} - T\frac{d^3z}{dx^3} + P\frac{d^2y}{dx^2} - \frac{m\omega^2}{g}y = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

If the shaft were straight, and subject to thrust T and twisting couple G, then, if performing harmonic lateral vibrations, the terms $\frac{m\omega^2}{g}y$, $\frac{m\omega^2}{g}z$ would represent the forces arising from the inertia of vibration; and thus it may be seen that the number of revolutions which would make the straight form of the shaft unstable by centrifugal whirling is exactly the same as the number of lateral

T 2

vibrations the shaft would make if still and slightly displaced; the same thrust and couple acting on the shaft in both cases.*

If the angular velocity is sufficiently small for ω^2 to be neglected, the equations (5) and (6) become

$$\mathrm{L}\frac{d^2z}{dx} + \mathrm{T}\frac{dy}{dx} + \mathrm{P}z = \text{const.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$\mathrm{L}\frac{d^2y}{dx} - \mathrm{T}\frac{dz}{dx} + \mathrm{P}y = \text{const.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

and these constants may be made zero by a suitable choice of origin.

If T = 0, we have the case discussed in § 3, namely that of the stability of a shaft subject only to a thrust P, and then—

$$\frac{\pi^2}{l^2} = \frac{\mathrm{P}}{\mathrm{L}},$$

l being the length of the shaft between the bearings.

If T be not zero, then the solution of (11) and (12) will be found subsequently, in § 5, to be given by

$$\frac{\pi^2}{l^2} = \frac{\mathrm{P}}{\mathrm{L}} + \frac{\mathrm{T}^2}{4\mathrm{L}^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

l being the length between bearings (Unwin's "Machine Design," § 45).

This formula (13) is the one to be employed for spacing out bearings, for shafting which does not run at a high speed.

Except in screw shafting, P the thrust is generally zero, and then the formula is simply—

$$\frac{\pi}{l} = \frac{\mathrm{T}}{2\mathrm{L}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

If P = 0 and T = 0, we have the case of a shaft slightly deformed from straightness by centrifugal whirling alone; and then both differential equations (9) and (10) lead to the same result—

$$\frac{d^4y}{dx^4} - \frac{m\omega^2}{g\mathrm{L}}y = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

the same as for the lateral vibrations of an unstrained bar.†

Two cases must here be distinguished.

(I.) If the bearings A and B of the shaft A B preserve the direction as well as the position of the shaft, then the problem is the same as

* Lord Rayleigh's "Theory of Sound," chapter viii.; Rankine's "Millwork," p. 549.

† Rayleigh, "Sound," chap. viii.; and Rankine, "Millwork."

that of the lateral vibrations of a clamped bar; and therefore, taking the origin O at the middle of the shaft between the bearings, the equation of the curve A P B, assumed by the central line of the shaft, will be of the form $y = b \cosh \mu x + a \cos \mu x$,

$$\text{where } \mu^4 = \frac{m\omega^2}{gL}.$$

The condition that $y = 0$ at the ends A and B, where $x = \pm \frac{1}{2} l$, makes the equation of the form

$$y = a\left(\frac{\cosh \mu x}{\cosh \frac{1}{2}\mu l} - \frac{\cos \mu x}{\cos \frac{1}{2}\mu l}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

and then

$$\frac{dy}{dx} = \mu a\left(\frac{\sinh \mu x}{\cosh \frac{1}{2}\mu l} + \frac{\sin \mu x}{\cos \frac{1}{2}\mu l}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

The condition that $\frac{dy}{dx} = 0$ at A and B leads to the equation

$$\tanh \tfrac{1}{2}\mu l + \tan \tfrac{1}{2}\mu l = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

The least positive root of this equation is*

$$\tfrac{1}{2}\mu l = 4 \cdot 73$$

and therefore $\omega^2 = \frac{g L \mu^4}{m} = \frac{g L}{m l^4}(\mu l)^4$

and $l^2\omega = 89 \cdot 5 \sqrt{\left(\frac{g L}{m}\right)} \quad . \quad . \quad . \quad . \quad . \quad (19)$

If the shaft be making N revolutions per minute, then

$$\omega = \frac{2 N \pi}{60},$$

and $l^2 N = 89 \cdot 5 \times \frac{30}{\pi} \sqrt{\frac{g L}{m}}$

For a solid shaft of iron, d inches in diameter,

$$k^2 = \tfrac{1}{16} d^2, \quad L = E A k^2, \quad \text{and } m = AW,$$

where W = lbs. weight per cubic inch = $0 \cdot 28$ about,

and E = 30,000,000.

Therefore $\sqrt{\frac{gL}{m}} = 50{,}857\, d,$

and $l^2 \frac{N}{d} = 43{,}462{,}000;$

or $l \sqrt{\frac{N}{d}} = 6592.$

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* Rayleigh, "Sound," vol. i., p. 223.

If l be given in feet, then

$$l = 549\sqrt{\frac{d}{N}}.$$

(II.) If the bearings A and B preserve only the position of the shaft, and allow of a certain amount of play in direction, then the curvature of the central line at A and B will be zero; and we must assume, as the equation of the central line A Q B, the equation

$$y = a \cos \mu\, x,$$

or $$y = a \cos \pi \frac{x}{l},$$

where $$\frac{\pi^4}{l^4} = \frac{m\omega^2}{g\mathrm{L}}.$$

Therefore $$\omega = \frac{\pi^2}{l^2}\sqrt{\frac{g\mathrm{L}}{m}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

For a solid iron shaft, d inches in diameter, making N revolutions per minute,

$$l^2\,\mathrm{N} = 30\,\pi\sqrt{\frac{g\mathrm{L}}{m}}$$

and $$\sqrt{\frac{g\mathrm{L}}{m}} = 50857\,d,$$

therefore $$l^2\,\frac{\mathrm{N}}{d} = 4793200$$

$$l\sqrt{\frac{\mathrm{N}}{d}} = 2189\cdot3.$$

If l be given in feet,* $$l = 182\sqrt{\frac{d}{\mathrm{N}}}.$$

5. *Solution of the differential equations for combined Thrust and Twisting.*

The differential equations to be considered are

$$\mathrm{L}\frac{d^2z}{dx^2} + \mathrm{T}\frac{dy}{dx} + \mathrm{P}z = 0 \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$\mathrm{L}\frac{d^2y}{dx^2} - \mathrm{T}\frac{dz}{dx} + \mathrm{P}y = 0 \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Multiplying by $\frac{dz}{dx}$ and $\frac{dy}{dx}$ and adding,

$$\mathrm{L}\left(\frac{dy}{dx}\,\frac{d^2y}{dx^2} + \frac{dz}{dx}\,\frac{d^2z}{dx^2}\right) + \mathrm{P}\left(y\frac{dy}{dz} + z\frac{dz}{dx}\right) = 0,$$

* Unwin's "Machine Design," 4th ed., p. 212.

and integrating, $$L\left\{\left(\frac{dy}{dx}\right)^2+\left(\frac{dz}{dx}\right)^2\right\}+P\,(y^2+z^2)=C,$$

or $$L\left(\frac{dr}{dx}\right)^2+Lr^2\left(\frac{d\theta}{dx}\right)^2+Pr^2=C, \quad . \quad . \quad . \quad . \quad . \quad (21)$$

putting $y = r\cos\theta$, $z = r\sin\theta$.

Again, multiplying (11) by y and (12) by z, and subtracting,

$$L\left(y\frac{d^2z}{dx^2}-z\frac{d^2y}{dx^2}\right)+T\left(y\frac{dy}{dx}+z\frac{dz}{dx}\right)=0,$$

and integrating, $$L\left(y\frac{dz}{dx}-z\frac{dy}{dx}\right)+\tfrac{1}{2}T\,(y^2+z^2)=D,$$

or $$L\,r^2\frac{d\theta}{dx}+\tfrac{1}{2}Tr^2=D,$$

or $$\frac{d\theta}{dx}=\frac{D}{Lr^2}-\frac{T}{2L}. \quad . \quad . \quad . \quad . \quad . \quad (22)$$

Therefore $$L\left(\frac{dr}{dx}\right)^2+Lr^2\left(\frac{D}{Lr^2}-\frac{T}{2L}\right)^2+Pr^2=C,$$

or $$\tfrac{1}{4}\left(\frac{dr^2}{dx}\right)^2+\left(\frac{P}{L}+\frac{T^2}{4L^2}\right)r^4-\frac{TD}{L^2}r^2-\frac{Cr^2}{L}+\frac{D^2}{L^2}=0;$$

the solution of which is—

$$r^2=a^2\cos^2(\mu x-\alpha)+b^2\sin^2(\mu x-\alpha)$$

where $$\mu^2=\frac{P}{L}+\frac{T^2}{4L^2},$$

and a, b, and α are arbitrary constants, such that

$$\mu\,a\,b=\frac{D}{L}.$$

For $$a^2-r^2=(a^2-b^2)\sin^2(\mu x-\alpha),$$
$$r^2-b^2=(a^2-b^2)\cos^2(\mu x-\alpha),$$

and $$\tfrac{1}{2}\frac{dr^2}{dx}=-\mu\,(a^2-b^2)\sin(\mu x-\alpha)\cos(\mu x-\alpha)$$
$$=-\mu\sqrt{(a^2-r^2)(r^2-b^2)}$$

or $$\tfrac{1}{4}\left(\frac{dr^2}{dx}\right)^2+\mu^2(r^2-a^2)(r^2-b^2)=0;$$

Therefore $$\mu^2=\frac{P}{L}+\frac{T^2}{4L^2}$$
$$\mu^2a^2b^2=\frac{D^2}{L^2}.$$

Then
$$\frac{d\theta}{dx} = \frac{\mathrm{D}}{\mathrm{L}r^2} - \frac{\mathrm{T}}{2\mathrm{L}}$$
$$= \frac{\mu\ ab}{a^2 \cos^2(\mu x - \alpha) + b^2 \sin^2(\mu x - \alpha)} - \frac{\mathrm{T}}{2\mathrm{L}}$$
$$= \frac{\mu \dfrac{b}{a} \sec^2(\mu x - \alpha)}{1 + \dfrac{b^2}{a^2} \tan^2(\mu x - \alpha)} - \frac{\mathrm{T}}{2\mathrm{L}}.$$

Integrating, $\theta = \tan^{-1}\left\{\frac{b}{a}\tan(\mu x - \alpha)\right\} - \frac{\mathrm{T}x}{2\mathrm{L}} + \beta,$

where β is another arbitrary constant. We may write this
$$\theta = \cos^{-1}\left\{\frac{a}{r}\cos(\mu x - \alpha)\right\} - \frac{\mathrm{T}x}{2\mathrm{L}} + \beta;$$
or
$$\theta = \sin^{-1}\left\{\frac{l}{r}\sin(\mu x - \alpha)\right\} - \frac{\mathrm{T}x}{2\mathrm{L}} + \beta;$$
and therefore
$$\cos\theta = \frac{a}{r}\cos(\mu x - \alpha)\cos\left(\frac{\mathrm{T}x}{2\mathrm{L}} - \beta\right) + \frac{b}{r}\sin(\mu x - \alpha)\sin\left(\frac{\mathrm{T}x}{2\mathrm{L}} - \beta\right);$$
or
$$y = r\cos\theta$$
$$= a\cos(\mu x - \alpha)\cos\left(\frac{\mathrm{T}x}{2\mathrm{L}} - \beta\right) + b\sin(\mu x - \alpha)\sin\left(\frac{\mathrm{T}x}{2\mathrm{L}} - \beta\right),$$
and
$$z = r\sin\theta$$
$$= -a\cos(\mu x - \alpha)\sin\left(\frac{\mathrm{T}x}{2\mathrm{L}} - \beta\right) + b\sin(\mu x - \alpha)\cos\left(\frac{\mathrm{T}x}{2\mathrm{L}} - \beta\right);$$
or $y = \frac{1}{2}(a - b)\cos(m_1 x - \alpha - \beta) + \frac{1}{2}(a + b)\cos(m_2 x + \alpha - \beta),$
$$z = -\tfrac{1}{2}(a - b)\sin(m_1 x - \alpha - \beta) - \tfrac{1}{2}(a + b)\sin(m_2 x + \alpha - \beta),$$
where
$$m_1 = \frac{\mathrm{T}}{2\mathrm{L}} + \mu, \text{ and } m_2 = \frac{\mathrm{T}}{2\mathrm{L}} - \mu;$$
and therefore m_1, m_2 are the roots of the quadratic equation
$$\mathrm{L}m^2 - \mathrm{T}m - \mathrm{P} = 0.$$

If r can vanish, we can put $b = 0$, and then
$$r = a\cos(\mu x - \alpha)$$
$$\theta = -\frac{\mathrm{T}x}{2\mathrm{L}} + \beta.$$

Hence $y = \frac{1}{2}a\left\{\cos(m_1 x - \alpha - \beta) + \cos(m_2 x + \alpha - \beta)\right\},$
$$z = -\tfrac{1}{2}a\left\{\sin(m_1 x - \alpha - \beta) + \sin(m_2 x + \alpha - \beta)\right\}.$$

If $r = 0$, when $x = \pm\frac{1}{2}l$, then $\alpha = 0$, and $\mu l = \pi$;

or $$\frac{\pi^2}{l^2} = \frac{P}{L} + \frac{T^2}{4L};$$

and $$y = \tfrac{1}{2}\, a \left\{\cos(m_1 x - \beta) + \cos(m_2 x - \beta)\right\},$$

$$z = -\tfrac{1}{2}\, a \left\{\sin(m_1 x - \beta) + \sin(m_2 x - \beta)\right\}.$$

In the most general case the values of y and z are of the form

$$y = A\cos m_1 x + B\cos m_2 x + C\sin m_1 x + D\sin m_2 x,$$

$$z = -A\sin m_1 x - B\sin m_2 x + C\cos m_1 x + D\cos m_2 x,$$

where A, B, C, D are arbitrary constants; as might have been seen immediately from the solution of the simultaneous linear differential equations (11) and (12). For the assumptions

$$y = \cos mx,\quad z = -\sin mx,$$

or $$y = \sin mx,\quad z = \cos mx,$$

both lead to the same quadratic

$$L m^2 - T m \mp P = 0,$$

when substituted in (11) and (12).

The terminal conditions of the shaft due to the presence of the bearings must now be discussed.

The bearings may be supposed to operate in three different ways.

(1.) The bearings may be supposed fixed in position, but allowing of a certain amount of play of direction: operating in fact as if universal joints.

(2.) The bearings may be supposed to have side play, but to preserve the direction of the shaft rigidly parallel to its original direction.

(3.) The bearings may be supposed to allow of no play at all, either sideways or in direction.

(1.) In the first case, where the bearings allow of play of direction, r vanishes at the bearings, where $x = \pm \tfrac{1}{2} l$, l being the length of shaft between bearings; and therefore $b = 0$, and

$$r = a\cos(\mu x - \alpha).$$

But since $r = 0$, where $x = \pm \tfrac{1}{2} l$,

therefore $$\alpha = 0, \text{ and } r = a\cos \mu x.$$

Also $$\theta = -\frac{Tx}{2L} + \beta,$$

and β may be made to vanish by a proper choice of direction of axis.

Hence $$\theta = -\frac{Tx}{2L},$$

and $$r = a \cos \frac{2\mu L}{T}\theta,$$

the polar equation of the projection of the spiral line formed by the central line of the shaft on a plane perpendicular to the axis of x, as in Fig. 10, Plate 18.

Then $$y = \frac{1}{2} a (\cos m_1 x + \cos m_2 x),$$

$$z = -\tfrac{1}{2} a (\sin m_1 x + \sin m_2 x),$$

or $$y = a \cos \mu x \cos \frac{Tx}{2L},$$

$$z = - a \cos \mu x \sin \frac{Tx}{2L},$$

and $$r = a \cos \mu x,$$

where $$\mu^2 = \frac{P}{L} + \frac{T^2}{4L^2}.$$

Since y, z, and r all vanish simultaneously when $x = \pm \frac{1}{2} l$, therefore $\mu^2 = \frac{\pi^2}{l^2}$, giving $\frac{\pi^2}{l^2} = \frac{P}{L} + \frac{T^2}{4L^2}$, which is the required condition stated above.

(2.) In the second case, where the bearings are supposed to allow of side play only, preserving the direction of the shaft, the terminal conditions are that

$$\frac{dy}{dx} = 0, \text{ and } \frac{dz}{dx} = 0, \text{ when } x = \pm \tfrac{1}{2} l.$$

Therefore we may put

$$y = A \cos m_1 x + B \cos m_2 x + C \sin m_1 x + D \sin m_2 x,$$
$$z = - A \sin m_1 x - B \sin m_2 x + C \cos m_1 x + D \cos m_2 x ;$$

and the above conditions lead to the equations

$$m_1 A \sin \tfrac{1}{2} m_1 l + m_2 B \sin \tfrac{1}{2} m_2 l = 0,$$
$$m_1 A \cos \tfrac{1}{2} m_1 l + m_2 B \cos \tfrac{1}{2} m_2 l = 0,$$
$$m_1 C \sin \tfrac{1}{2} m_1 l + m_2 D \sin \tfrac{1}{2} m_2 l = 0,$$
$$m_1 C \cos \tfrac{1}{2} m_1 l + m_2 D \cos \tfrac{1}{2} m_2 l = 0,$$

and therefore $$\frac{m_1 A}{m_2 B} = \frac{m_1 C}{m_2 D} = -\frac{\sin \frac{1}{2} m_2 l}{\sin \frac{1}{2} m_1 l} = -\frac{\cos \frac{1}{2} m_2 l}{\cos \frac{1}{2} m_1 l};$$

or $$\sin \tfrac{1}{2} (m_1 - m_2) l = 0,$$

$$\tfrac{1}{2} (m_1 - m_2) l = l = n \pi.$$

Taking $n = 1$, the least positive value, we have $\mu\, l = \pi$,

or
$$\frac{\pi^2}{l^2} = \mu^2 = \frac{\mathrm{P}}{\mathrm{L}} + \frac{\mathrm{T}^2}{4\mathrm{L}^2},$$
as in the first case.

Then $$m_1\, \mathrm{A} = m_2\, \mathrm{B}, \quad m_1\, c = m_2\, \mathrm{D};$$
so that we may put
$$y = c\left(\frac{\cos m_1 x}{m_1} + \frac{\cos m_2 x}{m_2}\right) + d\left(\frac{\sin m_1 x}{m_1} + \frac{\sin m_2 x}{m_2}\right)$$
$$z = -\, c\left(\frac{\sin m_1 x}{m_1} + \frac{\sin m_2 x}{m_2}\right) + d\left(\frac{\cos m_1 x}{m_1} + \frac{\cos m_2 x}{m_2}\right).$$

By turning the axes of y and z, we may make $z = 0$ when $x = 0$, and therefore $d = 0$; then
$$y = c\left(\frac{\cos m_1 x}{m_1} + \frac{\cos m_2 x}{m_2}\right)$$
$$z = -\, c\left(\frac{\sin m_1 x}{m_1} + \frac{\sin m_2 x}{m_2}\right);$$
and then $r^2 = c^2\left(\frac{1}{m_1} + \frac{1}{m_2}\right)^2 \cos \mu\, x + c^2\left(\frac{1}{m_1} - \frac{1}{m_2}\right)^2 \sin^2 \mu\, x$;

so that $a = 0$, and $a = c\left(\frac{1}{m_1} + \frac{1}{m_2}\right)$, $b = c\left(\frac{1}{m_1} - \frac{1}{m_2}\right)$;

and therefore $b > a$.

The projection of the spiral formed by the central line of the shaft on a plane perpendicular to the axis of x will therefore be of the form shown in Fig. 11, Plate 18.

(3.) In the third case the bearings are rigidly fixed and allow no play, either of direction or of position. Then at the bearings, where $x = \pm\, \frac{1}{2}\, l$, we must have, as in the last case, $\frac{dy}{dx} = 0$ and $\frac{dz}{dx} = 0$; and, in addition, the values of y and z must be the same.

The spiral formed by the central line of the shaft must therefore be made up by piecing together two curves satisfying the conditions of the case; the two pieces being optical reflections of each other, seen in a plane mirror passing through this point of junction, and perpendicular to the axis of x.

Therefore, if b denotes the length of the shaft between the bearings in this case,
$$\frac{4\pi^2}{l^2} = \mu^2 = \frac{\mathrm{P}}{\mathrm{L}} + \frac{\mathrm{T}^2}{4\mathrm{L}^2}.$$

If $a^2 = b^2$, then $r^2 = a^2$; and therefore, if $a = b$,

$$y = a \cos m_2 x, \quad z = -a \sin m_2 x;$$

and if $a = -b$,

$$y = a \cos m_1 x, \quad z = -a \sin m_1 x.$$

Therefore $\dfrac{d\theta}{dx} = \pm \mu - \dfrac{T}{2L} = -m_2$ or $-m_1$;

and in either case the curve formed by the central line of the shaft is a uniform spiral.

6. *Solution of the differential equations for Combined Thrust and Twisting, when the influence of the angular Velocity of Rotation is taken into account.*

The differential equations to be considered are now

$$L\frac{d^4 z}{dx^4} + T\frac{d^3 y}{dx^3} + P\frac{d^2 z}{dx^2} - \frac{m\omega^2}{g} z = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$L\frac{d^4 y}{dx^4} - T\frac{d^3 z}{dx^3} + P\frac{d^2 y}{dx^2} - \frac{m\omega^2}{g} y = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

two simultaneous linear differential equations of the fourth order.

As before, the assumptions

$$y = A \cos px, \quad z = -A \sin px,$$

lead to the same equation for the determination of p, namely

$$L p^4 - T p^3 - P p^2 - \frac{m\omega^2}{g} = 0;$$

so that, if p_1, p_2, p_3, p_4 be the roots of this biquadratic in p, real or imaginary, the most general solution of the differential equations (9) and (10), subject to the conditions that y is an even function, and z an odd function of x, is

$$y = A \cos p_1 x + B \cos p_2 x + C \cos p_3 x + D \cos p_4 x,$$
$$z = -A \sin p_1 x - B \sin p_2 x - C \sin p_3 x - D \sin p_4 x.$$

The results of the problem therefore depend upon the roots of the biquadratic in p,

$$L p^4 - T p^3 - P p^2 - \frac{m\omega^2}{g} = 0.$$

This equation has two real roots and two imaginary roots, as is obvious from inspection of Fig. 12, Plate 18, where the curve has the equation

$$y = Lx^4 - Tx^3 - Px^2;$$

and the roots are the values of x when $y = \dfrac{m\omega^2}{g}$.

The real roots will be respectively greater than $\frac{T}{2L} + \mu$, and less than $\frac{T}{2L} - \mu$, where $\mu^2 = \frac{P}{L} - \frac{T^2}{4L}$.

The values of the real roots must be found by the ordinary methods of approximation, when the numerical value of L, T, P, and $\frac{m\omega^2}{g}$ are known; and then denoting the real roots by p_1 and p_2, and dividing the biquadratic by $(x - p_1)(x - p_2)$, we can solve the remaining quadratic and find $p \pm i\,q$, the imaginary roots.

Denoting $\frac{m\omega^2}{g}$ by c, and supposing it small enough for its square to be neglected, the biquadratic can be split into the two quadratics

$$L\,p^2 - T\,p + \frac{cTL}{P^2}\,p - P - c\,\frac{T^2 + PL}{P^2} = 0,$$

and
$$p^2 - \frac{cT}{P^2}\,p + \frac{c}{P} = 0.$$

The first quadratic will give p_1 and p_2, the real roots; and the second quadratic will give

$$p + i\,q = \frac{cT}{2P^2} \pm i\sqrt{\frac{c}{P}},$$

the imaginary roots.

We see that p may be neglected in comparison with q, so that the imaginary roots may be supposed to be $\pm\, i\sqrt{\frac{c}{P}}$, where c is small.

The solution of equations (9) and (10) will be of the form—

$$y = A\cos p_1 x + B\cos p_2 x + C\cos(p + iq)x + D\cos(p - iq)x,$$
$$z = -A\sin p_1 x - B\sin p_2 x - C\sin(p + iq)x - D\sin(p - iq)x;$$

or, in a real form,

$$y = A\cos p_1 x + B\cos p_2 x + C\cos p x\cosh q x + D\sin p x\sinh q x,$$
$$z = -A\sin p_1 x - B\sin p_2 x - C\sin p x\cosh q x + D\cos p x\sinh q x.$$

The determination of A, B, C, D will depend upon the nature of the bearings, and the three different kinds of bearings must be discussed as before.

For bearings of the first and second kind, the periodic terms only need be retained, and we may therefore put $C = 0$ and $D = 0$.

Then for bearings of the first kind, we must have $A = B$, and

$$y = A(\cos p_1 x + \cos p_2 x),$$
$$z = -A(\sin p_1 x + \sin p_2 x);$$

and for bearings of the second kind, we must have m_1 A $= m_2$ B, and

$$y = \mathrm{A}\left(\frac{\cos p_1 x}{p_1} + \frac{\cos p_2 x}{p_2}\right)$$

$$z = -\mathrm{A}\left(\frac{\sin p_1 x}{p_1} + \frac{\sin p_2 x}{p_2}\right);$$

and in each case the additional condition must obtain, that

$$\tfrac{1}{2}(p_1 - p_2)\, l = \pi,$$

or

$$\frac{\pi^2}{l^2} = \tfrac{1}{4}(p_1 - p_2)^2,$$

giving the maximum length of shafting between bearings for stability.

For the third kind of bearings, C and D must be retained, and the discussion becomes complicated and is omitted.

When the couple T $= 0$, the central line of the shaft will form a plane curve, and the biquadratic becomes

$$\mathrm{L}\, p^4 - \mathrm{P}\, p^2 - c = 0$$

or

$$p^2 = \frac{\mathrm{P}}{2\,\mathrm{L}} \pm \sqrt{\frac{\mathrm{P}^2}{4\mathrm{L}^2} + c}$$

$$= p^2 \text{ or } - q^2 \text{ suppose};$$

and then

$$y = \mathrm{A}\cos p\, x + \mathrm{B}\cosh q\, x.$$

(1.) For the bearings which allow play of direction only,

$$y = 0, \text{ and } \frac{d^2 y}{dx^2} = 0, \text{ when } x = + \tfrac{1}{2}\, l,$$

and therefore B $= 0$, and

$$y = \mathrm{A}\cos p\, x,$$

and

$$pl = \pi,$$

or

$$\frac{\pi^2}{l^2} = \frac{\mathrm{P}}{2\mathrm{L}} + \sqrt{\left(\frac{\mathrm{P}^2}{4\mathrm{L}^2} + \frac{m\omega^2}{g}\right)}.$$

(2). For bearings allowing side play only, preserving a fixed direction of the shaft, the bearings must be supposed to shift in opposite directions, and we must put

$$y = \mathrm{A}\sin p\, x + \mathrm{B}\sinh q\, x.$$

For the curve to be periodic in form, we must have B $= 0$, and

$$y = \mathrm{A}\sin p\, x,$$

and the condition that $\frac{dy}{dx} = 0$ when $x = \pm \frac{1}{2}\, l$ leads to $pl = \pi$,

or

$$\frac{\pi^2}{l^2} = \frac{\mathrm{P}}{\mathrm{L}} + \sqrt{\left(\frac{\mathrm{P}}{4\mathrm{L}^2} + \frac{m\omega^2}{g}\right)}$$

as in the case immediately preceding.

(3.) For bearings rigidly fixed,

$$y = \text{A} \cos p\,x + \text{B} \cosh q\,x,$$

subject to the conditions $y = 0$ and $\frac{dy}{dx} = 0$, when $x = \pm \frac{1}{2}\,l$.

Therefore $$y = a\left(\frac{\cos p\,x}{\cos \frac{1}{2}\,pl} - \frac{\cosh q\,x}{\cosh \frac{1}{2}\,ql}\right),$$

and $$p \tan \tfrac{1}{2}\,pl + q \tan \tfrac{1}{2}\,ql = 0,$$

which determines l in terms of p and q.

Discussion on Strength of Shafting.

Professor Greenhill said that the formula given in the paper, which had arisen in some theoretical investigations, was easily and practically applicable. It differed from most formulæ in that no factor of safety was required, and that the dimensions could therefore be pushed to the extreme limits of the formula. At first sight, in screw-shafting it might appear that the quantity T, or the twisting moment, was the most important factor; but the numerical examples showed that the thrust P was far the more important of the two. Whether it would be found possible to utilise the formula, in order to space out bearings much further apart than was now customary, must be left for practical men to decide.

Mr. Clark had estimated (p. 185) that only 42 per cent. of the power of the engine was utilised in propelling the steam-ship. That might appear at first sight a great waste of power. But a simple theoretical investigation would show that at least 50 per cent. of the power must be thrown away in order to acquire the necessary reaction from a yielding substance like water to propel the vessel. He had added a few remarks on hollow shafting—a subject which was discussed before the Institution at the meeting at Barrow (Proceedings 1880, p. 346). The effect of a crack was shown by the paper to be slightly more detrimental in the case of a hollow than of a solid shaft. But on the other hand the hollow shaft had great counterbalancing advantages.

Mr. G. B. Rennie thought the members ought to be much obliged to Professor Greenhill for giving his theoretical calculations on the strength of a most important part of a steam-ship. He had told them several rather interesting things—first of all that a shaft 22 in. in diam. might be, so far as the thrust and twist were concerned, 371 ft. in length between the bearings, without other support. That was rather an astonishing thing for a practical engineer to consider. He thought however that most engineers took the view that the bearings should be considered not so much as meeting the twist or the thrust, but rather as bearing the weight of

the shaft. They were made circular merely for ease in manufacture; the cap was made of light construction, and rather to keep out the dirt and for lubrication than to hold the shaft down. With regard to the end-thrust, although vessels were still frequently made with thrust-bearings towards the middle of the ship, so that the thrust was taken along the whole length of the shaft, yet in many ships, especially in government ships, the whole thrust of the screw was taken on the stern-post by a bearing disc, fitted with wood; so that, practically speaking, there was no end-thrust on the shaft at all.

Mr. E. A. COWPER would venture to ask Prof. Greenhill whether he would be kind enough to apply his formula to a few actual ordinary examples of broken propeller shafts, and calculate whether they ought to have broken or not. With regard to any formula of that kind, he himself would not trust it without an example to prove that it was right. Without some such practical test he was not convinced that the theory was correct. Probably it was; but at any rate, some examples worked out to show whether certain shafts ought to break or not would be very valuable and interesting.

Prof. UNWIN said that Professor Greenhill had modestly spoken of himself as a mere theorist. In calculating the stresses of structures of that kind he thought engineers were all mere theorists; they had no experimental evidence of any kind whatever as to what was the resistance of very large and long shafts. It was making a very great assumption to say that the stresses found to exist in small specimens were exactly the same as those which existed in large shafts under conditions extremely different; and they ought to be extremely obliged to the "mere theorist" who came to improve their knowledge. He might be permitted to point out exactly where the theory was an advance on what they knew before. There was a known expression for the stress due to twisting and thrust combined. In a shaft in which there was at once a stress due to a thrust and to a twisting moment, the resultant was given by the formula $S = \frac{3}{8} s + \frac{5}{8} \sqrt{s^2 + 4 t^2}$, where s was the stress due to the thrust, and t was the stress due to the twisting moment. But Professor

Greenhill had attempted a much more difficult problem, namely to find the limit of stability of the shaft, under the combination of the torsion and the tendency to buckle. The result of his theory was certainly very astonishing. All engineers knew that in small shafts they must place the bearings pretty close. In fact in such shafts it was the tendency to bend which they had the most to take care of; and though they calculated the strength of the shaft from the twisting moment, they used an enormously large factor of safety in order to provide against the tendency to bend. But in the case of very large shafts this tendency was much reduced; and Professor Greenhill had found that they might use shafts of very great length, without any particular danger of their bending under the action of combined thrust and torsion. This was a fact they ought to bear in mind, and it certainly ought in some way to regulate practice.*

Mr. Rennie had mentioned that the numerous bearings were made chiefly to sustain the weight of the shaft. That might be true enough; but it should be remembered that numerous bearings had one very great objection. A ship was not like a factory on land, where, when the bearings were laid out, one could depend upon the line being kept. In older ships it was not uncommon, at all events in French practice, to place one or more universal couplings in the length of the shaft in order to get rid of the enormous friction

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* (Additional note by Prof. Unwin).—It is usual amongst practical engineers, in employing Euler's formula, to use a factor of safety. Supposing a factor 5 to be adopted, then the formula for the working load consistent with stability is

$$\frac{\pi^2}{l^2} = \frac{5\,P}{E\,I} + \frac{25\,T^2}{4\,E^2\,I^2}.$$

Applying this to the case of the *Servia's* shaft, we get

$$\frac{\pi^2}{l^2} = \frac{905{,}000}{E\,I} + \frac{25 \times 21{,}785{,}000^2}{4\,E^2\,I^2}$$

$$= 0 \cdot 00000248 + 0 \cdot 00000002227.$$

Whence l = 1986 in. = 165 ft.

It should be observed however that the factor of safety for long columns is fixed in a very arbitrary way; and though some factor of safety is undoubtedly necessary, to allow for straining actions not included in the reckoning, the precise value of the factor of safety which should be used is very badly determined.

sometimes arising at these bearings, in consequence of the hogging or sagging of the ship. Although this was not so great in modern ships, it must occur to a certain extent: and great part of the large frictional waste which was known to occur was doubtless due to the fact of the bearings being a little out of line. If therefore they could get rid of some of the bearings, it would be a practical advantage. It was a question whether, either by the practical suggestions which Professor Greenhill had made, or by some analogous mode, they could reduce the number of bearings, so as to save first cost, and also the friction—not friction due to the weight, but friction due to the bearings not being exactly in line after the ship had been some time at sea. He was not prepared at the moment to say exactly what suggestion could be adopted. Possibly the resting of the shaft on simple plane surfaces was not a practicable plan, and it would be better to make it rest on two inclined surfaces, because two such surfaces, placed at an angle of 120°, might be horizontally adjusted as they wore away. But the wear would not be great, if it was due only to the weight of the shaft and to its inertia during the pitching and rolling of the ship.

Mr. Edward Reynolds said that, as he had brought forward the subject of hollow shafts at the Barrow Meeting, he would again call attention to the matter for a few moments; but he wanted to repeat the protest he had made at Barrow, namely that in attacking any particular style of construction, he was very far from having any feeling against any particular constructors. Professor Greenhill had apologised to some extent for bringing so theoretical a paper before them; but he thought there was some use in it, if only to have it discussed; for unfortunately theoretical utterances were apt to lead people rather astray, unless their bearing upon practice was fully considered. Did any one suppose that since the introduction of screw propulsion any single shaft had ever broken from the combination of torsion and thrust? He believed such a thing never would happen to sound shafts of the usual proportions. Fig. 13, Plate 16, would illustrate the way in which shafts really got broken. During the recent bad weather, a large ship came into

Liverpool with the bolts in several of the couplings broken; not in the middle, where they were generally supposed to break, but in two places, as shown at A and B, Fig. 13, so that each bolt was in three pieces. That was the second time that this had happened to that ship; and another large ship, working out of the port of London, had had the same kind of thing happen. That showed pretty well the sort of strains which came on those shafts—they were simply cross-breaking strains; and the shaft would have broken just the same if it had been merely turned round without driving the ship at all. In the same bad weather another ship about the same size came to Liverpool. She happened to have excessively strong couplings and bolts, so that the shaft did not give way; and the result was that the tunnel shafts were so sprung that they had to be taken out.

He had referred to the subject of hollow shafts at Barrow, and he was glad he had been able to do so then; because that was before there was any report of any disaster having happened to shafts of that description. The breakages that had since come under his notice were all of crank-shafts. He did not know of any ships doing heavy work that were fitted with hollow tunnel-shafts. They had been fitted in Government ships, it was true; but they all knew what work Government ships did after the trial trip had once been run. Only three weeks after the meeting at Barrow, reports about hollow shafts began to come in; and from that time to the present all that he had himself heard about hollow shafts was a tale of disaster. He knew of one fleet of several ships, which were fitted with hollow crank-shafts by a maker whose name would guarantee that there was no want of skill or care; but every one of those shafts had come to grief. In one case the first notice of anything happening was that the whole engine was completely wrecked by the sudden breakage of the shaft. In another case the shaft broke in a place most unusual—square across the centre of the crank-pin. He had not the smallest hesitation in saying that that class of fracture was chiefly chargeable to the hollow shaft.

He had tried at Barrow to make his idea understood, that the reason why you should have a solid shaft for cases of that kind, where there were all sorts of twisting and bending strains, was

because a core of material not under strain was needed in the centre, to hold the shaft together after the fracture had commenced externally; whereas, if it was made in the horribly scientific fashion of having all the parts under an equal strain, as a matter of course it would break, if it did break, all at once.

He had that morning been to see a particular ship, in which about three years ago he had been asked to inspect the crank-shaft. This was of steel, forged solid, not built up; and having had very heavy work had started a crack. Upon drilling into the crack it was found to be about half an inch deep; upon which the superintending engineer agreed with him that it was perfectly safe for another voyage; so it worked for 26,000 miles, and then appeared to be no worse than before. Another ship, which would arrive home in about a fortnight's time, had iron crank-shafts which had shown flaws for some time back, but being regularly watched were worked up to the present time with perfect confidence; they would now be changed. That was the sort of condition that one hoped to get at in these matters. Every time those large engines came in, they were stripped and thoroughly examined, and in 99 cases out of 100 the practical result was, as in railway work, that the faults were found out in time to prevent accident. But when the first intimation received of failure was that their scientific structure was tumbling about their ears, he did not think that was a very desirable condition. The author had referred, p. 185, to the power available for the propulsion of a ship being only 42 per cent. of the whole; but it did not follow that the thrust on the shaft was reduced in that proportion. A very large proportion of the loss of power was due to the suction produced against the stern of the ship by the action of the propeller; especially with some of the rather scientific propellers which tried to gather water from the outside and suck it into a central column. Probably one half of the loss of power indicated in the paper—about 60 per cent. of the whole—was to be charged to that cause; and the thrust would be wanted on the shaft to put that extra propelling power on the ship.

He might be permitted to add a little actual information to the opinions he had expressed. Some of his friends had made the

suggestion that he ought to make some direct experiments on the relative value of solid and hollow shafts. Within the last few weeks he had made some shafts, getting the material as nearly as possible uniform, by taking the piece slotted out of a large solid crank, as at C D, Fig. 14, Plate 16, and drawing it out in the direction C D. Out of this part the forged a shaft 9 feet long; and the first discussion having arisen on the question of the "City of Rome," he made it one quarter the size of the "City of Rome's" 25-inch shaft, namely $6\frac{1}{4}$ inches diameter. One half was then bored out into a hole $3\frac{1}{2}$ in. diam., representing the 14-in. hole in the "City of Rome's" shaft. Then the two halves were treated throughout in precisely the same manner, turned up and well polished so as to get identity in diameter; finally they were cut in two, Figs. 15 and 16, and were tested with the same test as was usually applied to railway axles, namely the drop-test, with 3-ft. bearings. The result, as shown by Table I. annexed, was that the hollow shaft stood in all fourteen blows of a 1-ton weight falling from a height of 20 feet, and then broke at the fifteenth. The corresponding solid shaft stood twelve blows from 20 feet, two blows from 30 feet, two blows from 35 feet, and fourteen from 39 feet, making thirty in all, at which time it appeared uninjured; in fact they were tired out, and did not go farther. So far as his experience went, a solid shaft of that sort, $6\frac{1}{4}$ inches in diameter, tested with 1 ton falling from 39 feet on 3-feet bearings, ought to stand a hundred blows or more; but none of his friends had ever had patience to go beyond sixty-three.

The above result was verbally communicated to some friends, and they suggested that shafts of the same sectional area, not the same diameter, ought to be taken. He pointed out that that was abandoning the whole ground on which they advocated hollow shafts, namely that they cut away a core of almost useless material, and greatly reduced the weight without seriously reducing the strength. And in the case of the "City of Rome," to get the same sectional area with a hole of that proportion, they would require to enlarge the 25-inch hollow shaft to $31\frac{1}{4}$ in.; and if they thought of what the stern-tube and bearings would be like in that case, they would hardly advocate that course. He thought however that he would try a direct

TABLE I.

Comparative Tests of Solid and Hollow Shafts, supported on 3 ft. bearings under 1 ton falling weight.

No. of Blow.	Height of Fall.	SOLID SHAFT. $6\frac{1}{4}$ in. diam. Deflection before blow.	SOLID SHAFT. $6\frac{1}{4}$ in. diam. Deflection after blow.	HOLLOW SHAFT. $6\frac{1}{4}$ in. diam. outside, $3\frac{1}{2}$ in. inside. Deflection before blow.	HOLLOW SHAFT. $6\frac{1}{4}$ in. diam. outside, $3\frac{1}{2}$ in. inside. Deflection after blow.
No.	Feet.	inch.	inch.	inch.	inch.
1	20	0	$1\frac{3}{8}$	0	$1\frac{3}{4}$
2	”	$1\frac{3}{8}$	$\frac{3}{16}$	$1\frac{3}{4}$	$\frac{1}{8}$
3	”	$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{1}{8}$	$1\frac{3}{4}$
4	”	$1\frac{1}{4}$	$\frac{1}{8}$	$1\frac{3}{4}$	$\frac{3}{16}$
5	”	$\frac{1}{8}$	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{3}{4}$
6	”	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{3}{4}$	$\frac{1}{4}$
7	”	$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{1}{4}$	$1\frac{13}{16}$
8	”	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{13}{16}$	$\frac{1}{4}$
9	”	$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{1}{4}$	$1\frac{13}{16}$
10	”	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{13}{16}$	$\frac{1}{4}$
11	”	$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{1}{4}$	$1\frac{7}{8}$
12	”	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{7}{8}$	$\frac{5}{16}$
13	30	$\frac{3}{16}$	$1\frac{3}{4}$	$\frac{5}{16}$	$2\frac{3}{4}$
14	”	$1\frac{3}{4}$	$\frac{5}{16}$	$2\frac{3}{4}$	$\frac{1}{2}$
15	35	$\frac{5}{16}$	2	$\frac{1}{2}$	Broke.
16	”	2	$\frac{3}{8}$		
17	39	$\frac{3}{8}$	$2\frac{1}{4}$		
18	”	$2\frac{1}{4}$	$\frac{1}{2}$		
19	”	$\frac{1}{2}$	$2\frac{1}{4}$		
20	”	$2\frac{1}{4}$	$\frac{1}{2}$		
21	”	$\frac{1}{2}$	$2\frac{1}{4}$		
22	”	$2\frac{1}{4}$	$\frac{1}{2}$		
23	”	$\frac{3}{8}$	$2\frac{1}{4}$		
24	”	$2\frac{1}{4}$	$\frac{3}{8}$		
25	”	$\frac{3}{8}$	$2\frac{1}{4}$		
26	”	$2\frac{1}{4}$	$\frac{3}{8}$		
27	”	$\frac{3}{8}$	$2\frac{3}{8}$		
28	”	$2\frac{3}{8}$	$\frac{1}{2}$		
29	”	$\frac{1}{2}$	$2\frac{3}{8}$		
30	”	$2\frac{3}{8}$	$\frac{1}{2}$		
		No sign of fracture.			

TABLE II.

Comparative Tests of Solid and Hollow Shafts, supported on 3 ft. bearings under 1 ton falling weight.

No. of Blow.	Height of Fall.	SOLID SHAFT. $6\frac{1}{4}$ in. diam.		HOLLOW SHAFT. $7\frac{9}{16}$ in. diam. outside, $4\frac{1}{4}$ in. inside.	
		Deflection before blow.	Deflection after blow.	Deflection before blow.	Deflection after blow.
No.	Feet.	inch.	inch.	inch.	inch.
1	20	0	$1\frac{5}{8}$	0	$1\frac{1}{8}$
2	,,	$1\frac{5}{8}$	0	$1\frac{1}{8}$	0
3	,,	0	$1\frac{1}{2}$	0	$1\frac{1}{8}$
4	,,	$1\frac{1}{2}$	0	$1\frac{1}{8}$	0
5	,,	0	$1\frac{1}{2}$	0	$1\frac{1}{8}$
6	,,	$1\frac{1}{2}$	0	$1\frac{1}{8}$	0
7	,,	0	$1\frac{1}{2}$	0	$1\frac{1}{8}$
8	,,	$1\frac{1}{2}$	0	$1\frac{1}{8}$	Broke.
9	,,	0	$1\frac{1}{2}$		
10	,,	$1\frac{1}{2}$	0		
11	,,	0	$1\frac{1}{2}$		
12	,,	$1\frac{1}{2}$	0		
13	30	0	$2\frac{1}{8}$		
14	,,	$2\frac{1}{8}$	$\frac{1}{8}$		
15	35	$\frac{1}{8}$	$2\frac{3}{8}$		
16	,,	$2\frac{3}{8}$	$\frac{1}{8}$		
17	39	$\frac{1}{8}$	$2\frac{5}{8}$		
18	,,	$2\frac{5}{8}$	$\frac{1}{8}$		
19	,,	$\frac{1}{8}$	$2\frac{5}{8}$		
20	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
21	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
22	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
23	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
24	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
25	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
26	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
27	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
28	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
29	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
30	,,	$2\frac{5}{8}$	$\frac{3}{8}$		

TABLE III.

Comparative Tests of Solid and Hollow Shafts, supported on 3 ft. bearings under 1 ton falling weight.

No. of Blow.	Height of Fall.	SOLID SHAFT. 6¼ in. diam.		HOLLOW SHAFT. 6¼ in. diam. outside, 3¼ in. inside.	
		Deflection before blow.	Deflection after blow.	Deflection before blow.	Deflection after blow.
No.	Feet.	inch.	inch.	inch.	inch.
1	20	0	$1\frac{5}{8}$	0	2
2	,,	$1\frac{5}{8}$	0	2	0
3	,,	0	$1\frac{1}{2}$	0	$1\frac{13}{16}$
4	,,	$1\frac{1}{2}$	0	$1\frac{13}{16}$	0
5	,,	0	$1\frac{1}{2}$	0	2
6	,,	$1\frac{1}{2}$	0	2	0
7	,,	0	$1\frac{5}{8}$	0	$1\frac{7}{8}$
8	,,	$1\frac{5}{8}$	0	$1\frac{7}{8}$	0
9	,,	0	$1\frac{5}{8}$	0	2
10	,,	$1\frac{5}{8}$	0	2	0
11	,,	0	$1\frac{5}{8}$	0	$1\frac{7}{8}$
12	,,	$1\frac{5}{8}$	0	$1\frac{7}{8}$	0
13	30	0	$2\frac{1}{8}$	0	$2\frac{3}{4}$
14	,,	$2\frac{1}{8}$	$\frac{1}{4}$	$2\frac{3}{4}$	0
15	35	$\frac{1}{4}$	$2\frac{5}{8}$	0	3
16	,,	$2\frac{5}{8}$	$\frac{1}{4}$	3	0
17	39	$\frac{1}{4}$	$2\frac{5}{8}$	0	$3\frac{3}{8}$
18	,,	$2\frac{5}{8}$	$\frac{1}{4}$	$3\frac{3}{8}$	$\frac{1}{4}$
19	,,	$\frac{1}{4}$	$2\frac{5}{8}$	$\frac{1}{4}$	Broke.
20	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
21	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
22	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
23	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
24	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
25	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
26	,,	$2\frac{5}{8}$	$\frac{1}{4}$		
27	,,	$\frac{1}{4}$	$2\frac{5}{8}$		
28	,,	$2\frac{5}{8}$	$\frac{1}{2}$		
29	,,	$\frac{1}{2}$	$2\frac{5}{8}$		
30	,,	$2\frac{5}{8}$			

This Shaft was turned round 90° after every second blow.

experiment; and he got another piece of steel of the same class and treated in the same way; only the hollow shaft was here $7\frac{9}{16}$ in. outside diameter, with a $4\frac{1}{4}$-in. inside hole. To his surprise that hollow piece did not stand as well as the other had done, but broke at the eighth blow, as in Table II. annexed. It had occurred to him however that it might have been a little unfairly treated; it was slightly softer than the former specimen, and had suffered appreciably from flattening under the blows. Within the last week he had had the original experiment repeated under different conditions. Every blow bent the shaft about $1\frac{7}{8}$ inch in the 3 feet. After each blow it was reversed and straightened, and then turned at right angles; and so they got through the experiment without any appreciable flattening. There was obviously a gain by that process, as seen in Table III. annexed; for that shaft had gone through eighteen blows—twelve blows from 20 feet, two from 30 feet, two from 35 feet, and two from 39 feet—and then it broke at the nineteenth. The solid shaft remained apparently uninjured after thirty blows, as before.

Professor A. B. W. Kennedy said that he found there was a little difference of terms between himself and his friend Mr. Reynolds. When the latter came across anything that failed, he called it "scientific;" whereas when he himself came across anything which failed, he rather believed it was because it was unscientific. A formula was not scientific in itself, and must be quite unscientific if wrongly applied; and after all that was the question to which in practical matters one had usually to address oneself. It was with some diffidence that he ventured to differ from Professor Greenhill and Professor Unwin, who were very much better mathematicians than himself. He must say however that, apart altogether from the practical suggestions at the end of the paper, the results assumed seemed hardly to be justified by the working out of the formula. Professor Greenhill's formula, p. 182, consisted of two parts. The first part, as was stated, was the ordinary Euler formula for a long column, and the second part was the addition made to allow for the effects of twisting. But, as pointed out on page 186, in an actual

example, the second part amounted only to $\frac{1}{3000}$th of the first part; so that it might be entirely disregarded. He had himself worked out the same quantities for the first example; and he found that the second part of the formula was only $\frac{1}{500}$th of the first, so that it only amounted to $\frac{1}{5}$ per cent. The whole question then, unless he was mistaken, resolved itself simply into a calculation of the length of a long strut by the ordinary formula of Euler. It amounted to saying that in that particular case a column $22\frac{1}{2}$ inches diameter and 370 feet long would support a thrust of 181,000 lbs., or about 81 tons, without buckling. So that he did not think they had got anything very new brought before them. The question was, what the formula of Euler really came to. It was not a formula which one could make use of under ordinary circumstances for designing a strut; because it assumed that the length of the strut was very great in proportion to its diameter—so great that at a certain load, below the limit of elasticity, an elastic bending could take place under end-long stress. Now that, he thought, was rather a condition which it was desirable to avoid in engineering work: it was preferable to make struts, which were designed as struts, so stiff that they should compress directly and should not buckle; and especially in a shaft elastic bending from any cause had to be eliminated, and therefore it was needful more or less to stiffen the shaft at intervals. These intervals might be much too short—that was another question; but the shaft thus came into a condition in which, unless his view of the matter was wrong, the formula was inapplicable.

The point, perhaps, might be seen a little more clearly by looking at it from another point of view. The formula included no quantity depending on the strength of the material used. It included the modulus of elasticity, and it included also the moment of inertia and other quantities which depended merely on the form. But the modulus of elasticity for steel of all qualities was practically identical with that for iron: he believed no experimental difference was found between them. If therefore the strength of a shaft depended on considerations which were included in Euler's formula, they were wasting material in making it of steel: iron would do as well. If

on the other hand they were right in using the stronger metal, it must be because the strength of a shaft was dependent chiefly on considerations other than its resistance as a long strut.

As to the second half of the paper, he thought that the question of hollow *versus* solid shafts could hardly be settled by a purely mathematical treatment. There was a great deal to be said for the contention of Mr. Reynolds, which was really an attempt to look at the physical as well as the mathematical side of the question. There was undoubtedly an action between the unstrained parts and the strained parts of a material, which he was afraid they did not well understand. He had found in the case of riveted joints, for example, that the metal left between the holes in the plate was apparently stronger than it had been before: the additional strength being no doubt more or less directly due to the support which the unstrained part gave to the strained part. In beams again, as was well known, the actual calculated breaking stress per square inch was always a stress much greater than the metal could stand in pure tension; and in shafts, where the metal was twisted asunder, the calculated maximum shearing stress per square inch was always 40 per cent. or so in excess of the shearing stress which the metal could stand in direct shear. For instance, a piece of rivet steel, which would shear at 20 tons per sq. in., would give a calculated shearing stress at the outside of perhaps 26 or 28 tons, if it were shorn asunder not by direct shearing but by being twisted. That he took to be due—in a manner which he confessed he did not understand—to the action of the inner and unstrained portion of the material in helping the outer and most strained layers. Now this of course was not taken into account in Professor Greenhill's paper; but he submitted that it probably formed an essential part of the subject, and a part which would have to be taken into account before one could form a "scientific" opinion on the question between hollow and solid shafts.

Mr. Arthur Paget said he supposed Mr. Reynolds had been endeavouring by his experiments to contribute to their knowledge of the endurance of hollow and solid screw-shafts; but, if he understood him rightly, he had experimented with the samples in

question in a way which showed nothing but their transverse strength, when exposed to blows between supports. Now this was the one strain to which a screw-shaft was never exposed; therefore with a view to any comparison between hollow shafts and solid ones he ventured to think that the experiments were simply misleading. If he had understood the experiments rightly, there was neither torsion nor end-thrust used, but simply a transverse strain of the material by impact, which was a strain to which screw-shafts were not exposed.

Mr. Reynolds said a transverse strain was one of the strains which a screw-shaft had to sustain.

Mr. Henry Shield did not wish it to go forth as the undisputed opinion of practical men in the Institution that hollow shafts had only led to a series of disasters. In the great majority of cases, in his own practice, he was using solid shafting; but he could point to cases of hollow crank-shafts that had been doing exceedingly good work for many years, without intermission or interruption of any sort or kind; that was a positive fact which he thought it as well to mention, because he did not think that such a statement should go forth uncontradicted. In Liverpool they had a good deal of experience of all kinds of shafting, hollow and solid, and he might say that it had fallen to his lot to find himself almost able to put his hand into a hole inside a big solid steel shaft. He was not going to say by whom it was made, except that he believed it was made with the very greatest care. It had also fallen to his lot to see hollow shafting which had given way after a very short experience; in some cases he thought he had been able to trace the result to bad lubrication and heating of the shafting. He agreed with Professor Kennedy that they ought to take great account of sagging, and of the uneven bed on which the shaft was lying. He thought it was exceedingly desirable to have theoretical papers like the present, and they were much indebted to any one who brought them forward, because it was only by trying those theoretical considerations in the light of practice that they could make any progress at all.

Professor UNWIN said Professor Kennedy had stated that Euler's formula contained no term depending on the strength of the material; and therefore it would give the same dimensions for iron and steel. He asked leave to point out that the way in which the strength of the material came in, in the use of Euler's formula, was that there was a defined ratio of length to diameter beyond which the formula must not be used; and that limit was different for iron and for steel. Now where the length of a column was more than thirty-six to forty-eight times the diameter, and the stress, as in that case it would be found to be, below the ordinary working limit, he believed there was no evidence to show—he challenged Professor Kennedy to produce any—that a steel shaft was any better than a wrought-iron one. The strength of the shaft and the number of bearings necessary for stability were two different questions.

Professor KENNEDY said he did not wish to convey any imputation on the formula, nor on the statement just made by Professor Unwin, that a steel column and a wrought-iron column might be equally good under the conditions named; but he rather protested against the idea that a shaft was to be treated simply as a long column, and that therefore one might apply the formula to that case equally well.

Professor GREENHILL, in reply, said he felt much flattered that practical men of eminence should have offered such valuable remarks on the theory which he had put forward. He took most of those remarks to be confirmatory of the views which he had advanced. Mr. Reynolds had said that screw-shafts never broke from thrust or torsion, but that they broke from the strains put on them by the ship. It was just for that reason that he had ventured to suggest the suppression of so many intermediate points of support, all acting as points of application of pressure, which would snap the shaft when the ship was strained beyond a certain limit. There was still ample stiffness in the shaft against the combined torsion and thrust (not against the effect of gravity) with the suppression of the intermediate bearings; and the suppression of those bearings left the shaft much more flexible, and much more capable of bending

with the bending and strain of the ship, than was the case previously. Professor Kennedy had pointed out with perfect justice that when they came to apply the formula to practice, Euler's original formula was sufficient for the purpose of calculating the stiffness; but he maintained that a complete theoretical investigation was necessary before anybody could pronounce that the twisting moment might be neglected, as turned out to be the fact.

He would not venture to enter into the controversy as to hollow and solid shafts; but it should be remembered that as the size of any structure was increased, the strength, comparatively speaking, diminished; and where they were limited in weight, and at the same time were constrained to have a certain strength, that strength must be attained by a better disposition of the material. That was what was attempted by the hollow shaft. Similar instances of improvement in the disposition of the same amount of material might be seen everywhere. The cross-section of an ordinary rail, or an ordinary girder, was another application of the same principle.

The President said as a general rule the papers put before the Institution were intensely practical; but it was certainly very desirable that practice should be refined by theory, and that theory should be strengthened by practice. He therefore thought that a paper like the present should be hailed, as he was sure it was hailed, with satisfaction by the members of the Institution, and he called upon them to return their best thanks to Professor Greenhill for the trouble he had taken.

ON SOME MODERN SYSTEMS OF CUTTING METALS.

BY MR. W. FORD SMITH, OF MANCHESTER.

In this paper it is proposed to treat of some of the processes of Cutting Metals which the writer has adopted since he read a paper on Tool-holders before the Institution (Proceedings, 1866, p. 288). The success of the round tool-holders then described has led to the further adoption of mechanical means of making and maintaining the tools used in various machines for cutting and finishing metals in their cold state. Such machines are commonly known by the term "machine tools;" and comprise lathes, planing, shaping, and slotting machines, milling machines, drilling and boring machines, screwing and chasing machines, &c.

TOOL-HOLDERS AND CUTTERS.

The former paper mainly described what have since become known as right- and left-hand round tool-holders. They are used in different machine tools principally for "roughing out," or, in other words, for rapidly reducing castings, forgings, &c., from their rough state to nearly their finished forms and dimensions. The tool-holders are called round from their cutters being made of round steel cut from the bar. Notwithstanding that they are very widely applicable, take heavy cuts, and do the bulk of all machine-work in lathes, and in planing, shaping, and slotting machines, it was soon found that they could not compass the whole of the work required in the shops; and it was therefore necessary still to allow the use of some of the common forged tools in conjunction with the round tool-holders. This however was objectionable, as no positive rule could then be laid down to define what number of forged tools should be allowed to each workman; and it became apparent that the tool-

holder system, in order to reach the highest degree of efficiency, must be made complete and independent in itself. This led to the designing of another tool-holder of the most general kind the writer could devise, in the hope thereby to complete the system.

With this object in view, all the remaining forged tools then in use were collected together, and the swivel tool-holder was schemed, Figs. 1 to 3, Plate 19, with cutters so adjustable that they could not only be swivelled round and then fixed to any desired angle, but could also be made to project at pleasure to any required distance in order to reach and cut into all sorts of difficult and awkward corners; in fact to machine any work which the round tool-holder could not finish. Two of the principal objects aimed at were to devise a system of cutters which should not require any forging or smithing, and should yet be capable of being adapted by the simplest possible means, and by grinding the ends only, to all forms which the round cutters would not meet. The special section of steel decided upon was a sort of deep V section, the lower part of which is slightly rounded, as shown in Fig. 4. The angles of the sides give the same amount of clearance (1 in 8) as that given in the round tool-holders, and this same angle of clearance is given to the ground parts. The section of the swivel cutter is made very deep, in order to obtain ample strength in the direction of the pressure it has to support when cutting, as shown by the arrows, Figs. 1 and 4. The angle of the cutter, as in Fig. 21, Plate 21, is 68°, and is common to every swivel tool-holder. In the cutter for the round tool-holder two angles had been fixed upon as standards, one to cut all kinds of wrought metals, the other all cast metals. To avoid complication however, in the swivel toolholders one cutting angle was fixed upon for all metals, and applied to all cutters. The angle selected, or 68°, is one differing slightly from that of the round cutters, but is that which worked out the best in practice. The cutters of the round tool-holders are found very advantageous in producing and finishing standard-size round corners in journals of shafts, &c., and in other cases, where the engineer of the present day is anxious to preserve all the strength possible in the parts; but there are still cases where square, angular, or undercut surfaces

must be produced, as illustrated in Figs. 5–11, Plate 19. These are front views showing the tool-holders at work planing or shaping. They are supposed to be travelling forward, or the work to be moving in the opposite direction; and the arrows in each view indicate the direction in which the tool-holder is being fed at each stroke of the machine, to take the next cut.

Fig. 5, Plate 19, shows the mode of planing the under horizontal surface of a lathe bed. The cutter shown in use is ground to an angle of 86°, or 4° less than a right angle, and thus has a clearance of 2° at each side when cutting either horizontally or vertically. This cutter is very general in its applicability, and is devised so as to finish with one setting both the vertical surface A, and the horizontal surface H, without the necessity for disturbing the cutter in any way. The ordinary system is to use at least two tools for roughing out, and two for finishing, on two surfaces at right angles with each other.

Fig. 6, Plate 19, shows the method of planing in a very limited space the under horizontal surface S; the corresponding surface B is planed afterwards, without disturbing the tool-holder in the tool-box, by simply slacking the nut, swivelling the bolt N half-way round, replacing the cutter with one of the opposite hand, and again securing it by the nut.

Fig. 7, Plate 19, shows a swivel tool-holder clearing without difficulty a boss which projects and would be very much in the way of any ordinary tool. The cutter in this case planes not only the horizontal surface C, but the inclined surface V also, with one setting and without being disturbed in the tool-box.

Fig. 8, Plate 19, shows the method of cutting a vertical slot in a horizontal surface of metal. The cutter in this case is called a parting tool. Fig. 9, Plate 20, is a side elevation of this same cutter, showing the cutting angle, which is 68°.

Figs. 10 and 11, Plate 19, are tool-holders with cutters of rather special forms. The former is shown planing out or under-cutting a T-shaped slot; and the latter is planing out a small rectangular clearance corner.

Figs. 12 and 13, Plate 20, show a swivel tool-holder with a round shank, such as is used on the slide-rest of a screw-cutting lathe, for

cutting square threads. It is carried on a wrought-iron or steel block, provided with a groove, semicircular in section, in which the round shank of the tool-holder lies, and is clamped down in the usual way. The cutters for cutting out the spaces between the square threads are of very simple form, and by aid of this tool-holder any tool made to the correct width of the space will cut either right-hand or left-hand screws, no matter whether they are single threads, double threads, or any other. To cover the same ground with forged tools, no less than six expensive cutters would be required, each one forged from square steel, and carefully filed up and hardened. With the tool-holder only one cutter is required, and it costs probably not more than 10 per cent. of one of the six forged tools, while it maintains its size much better, and consequently lasts much longer. It also takes off about twice the weight of cuttings per hour as compared with an ordinary forged tool. This system is useful where many screws of odd forms and pitches are required; but where there are sufficient numbers to be cut, special chasing lathes are far preferable to ordinary screw-cutting lathes, as they will do about six times as much chasing of V threads, or cutting of square threads, as can be accomplished in the ordinary lathe in the same time. Instead of carrying one chaser, the chasing lathes carry, in a chasing apparatus, three or four chasers; and these have their threads, whether square, V, rounded, or any other form, cut in their places by aid of a master tap. They are then tapered at the mouths, backed off, and hardened ready for work. The number of shavings cut simultaneously from a screw by this process varies from twelve to twenty-four, according to the size, strength, and pitch of the thread. Screws up to 6 in. diameter can be very rapidly cut by this system, on which very much more might be said if time permitted. A few screws cut by this process are exhibited.

When the two systems—the round and the swivel tool-holder—are worked in conjunction with each other, their universality of application is so thorough that almost every difficulty is met; and it was only in the case of paring and shaping articles in the slotting machine that two modifications had to be made in the holders, the same cutters being still applicable.

The Capstan-rest Chasing Lathes designed by the writer's firm have now become much used; and as a large amount of their work is produced from black bars of iron, steel, or other metals, each of which has to be finished at its extremities and cut or parted off, it was found advisable to make one special tool-holder, Figs. 14 to 17, Plate 21, for carrying tools of the correct sections to produce the desired shapes for the ends: the tedious and unreliable process of turning the ends with hand-turning tools is thus avoided. Each cutter is of absolutely the same section throughout its entire length, and the re-sharpening is done by grinding the end of the cutter only, so that it can only produce the same standard form as long as it lasts, that is to say till it is ground too short to be used any longer. The parting off might have been accomplished by the swivel tool-holder; but a special form, Figs. 18 to 20, is found to be more convenient in parting off close up to the chuck or lathe spindle.

To produce a maximum amount of cutting in a minimum space of time, there are two main points which must be carefully attended to. These seem to be applicable to all cutters for cutting metals, whether they happen to be those fixed rigidly in tool-boxes, as in turning-lathes, planers, shapers, slotters, &c.; or those which cut while they revolve, as milling-cutters, twist-drills, boring-bits, &c.

These two important points are:—

First, the cutting angle, or angle of the cutting surface, Fig. 21, Plate 21, *i.e.* that surface which removes the shavings of metal, and upon which the pressure of the cut comes, as shown by the arrow.

Secondly, the clearance angle, or angle of the clearance surface, *i.e.* that surface which passes over the surface of the metal that has been cut, and does not come in contact with the metal at all.

To produce the best results, and to ensure the utmost simplicity, it is important that these two angles be correctly constructed in the first instance. The best measure for both angles has been arrived at from actual practice and a series of experiments. When once obtained and started with, they should not alter by use, but should always remain constant, if the greatest amount of cutting efficiency is

to be attained. When aided by a mechanical system of re-grinding, and the use of standard angle-gauges, Figs. 22 and 23, Plate 21, there is no difficulty in maintaining the exact angles. The only changes which take place are that the cutters in tool-holders become gradually shorter by grinding, and that milling cutters during a long period of time become very gradually smaller in diameter, by the process of re-sharpening them on a fine emery-wheel. In the case of the tool-holders, as already explained, the cutting angle is maintained by the system of re-grinding, and the tool-holder itself always maintains the clearance angle. The system is thus simplified, as will be clearly understood when it is remembered that each one of the tool-holder cutters, no matter of what description, is ground on its end only. Thus the section is never altered, no smithing or alteration in form is necessitated, and consequently no repairing has to be done in the smith's shops.

The objects aimed at have been :—

1st. To produce the highest class of workmanship, by providing the best known form of cutters, carefully made, and capable of having their cutting edges accurately re-ground, so that the surfaces of the machined work may be produced direct from the cutters so highly finished that no hand-work could possibly improve them. Most of the turning of wrought iron, for instance, may be so perfectly finished that there is no necessity to polish it by means of emery or emery-cloth.

2nd. To make all the cutters so free from complication, and simple to keep in order, that no difficulty or error may occur in re-grinding them.

3rd. Since finely-polished surfaces cannot be obtained without the most perfect cutting edges, to make all cutters not only of the best steel, but with their cutting edges most accurately and carefully ground up, in almost all cases by mechanical means. The durability of the cutters, from their construction and high class of material, is very great, and they are thus capable of removing a great weight of metal in a given time.

The grinding or re-sharpening of all cutting edges is reduced to the greatest simplicity; and only three descriptions of machines

are requisite for this purpose. They are all arranged to grind mechanically; that is to say, the cutters while being ground are carried and pressed on the grindstone or emery-wheel by mechanism. The requisite forms and angles are also obtained by mechanism, it being found in practice that sufficient accuracy cannot be secured by hand-grinding.

The machines are as follows:—

1st. A grindstone with slide-rest, for grinding all the cutters used in tool-holders.

2nd. A twist-drill grinder; this also is by preference a grindstone, with mechanism for holding and guiding the twist-drills. A machine with an emery-wheel in place of the stone is also used for the grinding of twist-drills, with much the same mechanism for carrying the drills. In practice however the stone grinds about double the number of drills per hour, and with less risk of drawing the temper. Both stone and emery-wheel are run at a high speed, and used with water.

3rd. A small but very complete machine, one of which is exhibited, for re-grinding milling-cutters. In this case gritstone does not answer, and the grinding wheels are obliged to be of emery or corundum. They are very small in diameter, and many of them are exceedingly thin, and so delicate in form that if made of gritstone they would rapidly lose their shapes. They are run at a high speed, 3000 ft. per min., and are turned into form while revolving by means of a diamond.

A milling-cutter will work for a day, and in many cases for two days, before showing signs of distress. Before the cutting edges are visibly blunted, but as soon as the sense of touch indicates that their keenness is diminished,* the cutter should be put into this machine; and the probability is that not more than 1–1000 in. need be ground off each tooth, before it is restored again to a cutting edge almost as fine as that of a wood chisel. Each cutting edge, or in other words each tooth of the milling-cutter, is only passed rapidly

* The sense of touch, in passing the finger over the cutting edges, conveys the idea of slight bluntness better than it can be detected by the eye.

once or twice under the revolving wheel, which is itself of very fine emery. It can therefore be readily understood how delicate an operation this is, and why emery alone will answer for it.

In order to maintain the correct forms and angles of all cutters for tool-holders, sheet-steel angle-gauges, Fig. 22, Plate 21, are provided, and the process of grinding is thus reduced to a complete and exceedingly simple system. In well-regulated shops, a young man is selected to work each machine for cutter grinding; and in practice each man so engaged can keep a works employing 150 men (exclusive of moulders or boiler makers) well supplied with all the necessary cutting tools from day to day. A very great saving is thus effected, as no machine need ever stand idle for want of cutters, and no repairing of tools in the smithy is needed.

Take for instance an engineering works employing 250 men. The requisite number of improved grinding machines, with special mechanical appliances, is as follows:—

Two patent grindstones for re-sharpening cutters mechanically.

One patent twist-drill grinder for re-sharpening twist-drills mechanically.

One improved cutter-grinder with small emery-wheel, for re-sharpening the cutters used in milling machines.

To follow the system out satisfactorily, the man working the grindstone goes round to each machine every morning, collects together those cutters which have been blunted by use the previous day, carries them to his grindstone, re-sharpens them, and distributes them out again to each machine;—which is thus kept well stocked with an ample number of cutters, always ready for immediate use.

The cutters for tool-holders do not require any repairing in the smithy; consequently that operation, which is costly in so many ways, is avoided, and jobbing or tool smiths with their strikers are almost entirely dispensed with.

For re-hardening the cutters, a rule is made that when the grinder meets with cutters which are not as hard at their cutting points as they ought to be, he puts them on one side, and periodically, say once every fortnight, he sends the lot into the smithy for the end

of each to be re-tempered. This is a very inexpensive operation, the time occupied being about two hours per fortnight. They are placed in a small oven by dozens and very slowly heated up to a dull red; the end of each cutter is then plunged into a perforated iron box immersed in water till the bottom is covered to the required depth for hardening the cutter up to the proper distance from its point. The cutters are left standing in a nearly vertical position in the box of water, until they have gradually cooled down sufficiently to be removed. They are then sent to the grindstone, re-ground, and given out with the other cutters to be used again in the different machines. With steel of the highest quality for cutters, it is most important to keep it out of the smith's fire entirely, if possible. That object is here attained, the cutters never going to the fire except for re-hardening. During the life of a cutter it only sees the fire probably six times.

As the weight of each cutter is small, usually not more than from $\frac{1}{15}$th to $\frac{1}{20}$th that of a forged tool used for the same purpose, the outlay for best tool steel is not heavy; and the engineer is not tempted to purchase any but that of the highest quality. With such steel, especially when used in the best manner, each machine is capable of cutting at a high speed, and the cuts may be coarser than those ordinarily taken. When the swivel tool-holders were first used on planing machines, cutting slots 1 in. broad into solid castings, it was found that two teeth of the feed could be used at each stroke. Previously a forged tool of the same breadth, ground to form by the planer to the best of his ability, had been used in the same machines; but he found, on trial from time to time, that it was impossible to use more than one tooth of the feed; or, in other words, the tool-holder cut a given depth into the metal in half the time of the forged tool.

Again, when the swivel tool-holders were first used in cutting square-threaded screws, the utmost the lathe could do with ordinary forged tools, ground only by the judgment of each man and not to the best selected and standard angles, was to take four degrees of feed at each cut, as indicated by the micrometer feed-wheel. The tool-holder on the other hand took seven degrees of feed in the

same lathe, doing the same work, and producing quite as good or a better finish with the same expenditure of steam power.

The cutters for the swivel tool-holders can not only be made at the outset, but also constantly maintained, at the best and most efficient angles which practice can teach; it therefore follows that a very much better class of machine-work can be produced. The finished surfaces obtained from the tool-holders show a striking superiority over those from forged tools, especially when in the latter the angles are ground by hand, by each man or boy working a machine, who of course has not made a study of the best angles. The tendency then is to grind the cutters to all sorts of incorrect forms, which more or less tear the surfaces of the machined work, and leave bad finishes, such as require a considerable amount of hand-labour bestowed upon them afterwards, in filing, scraping, and polishing.

Again, the tool-holders have led up to a considerable extension of what is called Broad-finishing, in planing, turning, shaping, slotting, &c.

Broad-cutting feeds, varying from ½ in. to 1½ in. in width, are very commonly taken by the swivel tool-holders, and more accurate surfaces produced than with finer feeds. The advantages in point of time saved are very great; the time occupied in finishing by broad-cutting being from one-twelfth to one-twentieth of that consumed by finishing with ordinary feeds and in the usual manner. Some samples of this kind of finishing lie on the table, together with the cutter which was used.

The width of broad-cutting can be increased to any desired limit, and there have been special cases where it has been advantageous to take thin shavings 3 in. to 6 in. in width.

The principal limits to broad-cutting are as follows:—

1st. The power of grinding the cutting tool to a sufficiently straight or true cutting edge: the best plan of course is to do this by mechanical means.

2nd. The securing of sufficient stability in the machine tool to hold the broad-cutter so rigidly up to its work that neither the cutter itself nor the work may spring away, and that no jarring or

injurious vibration may be produced, and impart its evil effect to the finished surface.

3rd. The securing of sufficiently accurate work to answer the purpose for which it may be required. For instance, the piece of work planed or turned by this process may be a portion of a large railway bridge, where absolute accuracy is not requisite; or on the other hand it may be some portion of a machine tool, where the utmost accuracy is needed; or again, some part of an engine, where the builder is anxious to obtain all the accuracy which can possibly be produced direct from the machine tool.

Twist-Drills.

During the last thirty years many attempts have been made to introduce a better system of drilling and boring; and on this subject very much might be written if time permitted. Many engineers have used square bar-steel, which the blacksmith has twisted, and then flattened at one end to form a drill. The object of the twisted stem was to screw the cuttings out of the hole, and to some extent this succeeded, but not perfectly. The twisted square section revolving in the round hole had a tendency to crush or grind up the cuttings; and if they were once reduced to powder it was difficult (especially in drilling vertically) for the drill to lift the powdered metal out of the hole.

In most cases the lips of these drills were of such form that the cutting angle, or face of each lip, which ought to have been about 60°, Fig. 21, Plate 21, was 90°, or even still more obtuse: this being an angle which would scrape only, but could hardly be expected to cut sweetly or rapidly.

Again, there were attempts to make the cutting angles of the two lips of much the same number of degrees as that given by the twist itself in a good twist drill. This was done by forging or filing a semicircular or curved groove on the lower face F of each lip, Figs. 24 and 25, Plate 22. For a short time lips thus formed cut fairly well; but a very small amount of re-grinding soon put them out of shape, and made them of such obtuse cutting angles that good results could no longer be expected from them; and to be constantly sending

such drills to the jobbing or tool smith, and then to the fitter to file into form again before they were re-hardened, was found to be too tedious and too expensive. Again, to arrive at the best results in drilling, each of the cutting lips should make the same angle with a central line taken through the body of the drill; in other words, the angles A and B, Fig. 26, Plate 22, should each have exactly the same number of degrees, say 60°. The clearance angles also should be identical, and the leading point P should form the exact centre point of the drill. From practice it is found that, if these proportions are not correct, the drill cannot pierce the metal at more than about half the proper speed, and the hole produced will also be larger than the drill itself. To give an idea of the excessive accuracy which must be imparted to a twist-drill, we must bear in mind that even a good feed is only $\frac{1}{100}$ in. to each revolution; and as two lips are employed to remove this thickness of metal, each lip has only half that quantity to cut, or $\frac{1}{200}$ in. This $\frac{1}{200}$ in. is as much as can be taken in practice by each lip in drills of ordinary sizes. It will therefore be readily understood that if one lip of a drill stands before the other to the extent of $\frac{1}{200}$ in. only, the prominent lip, or portion of a lip, will have to remove the whole thickness of the metal from the hole at each turn. The lip of a drill will not stand such treatment; and it is therefore obvious that if this were attempted the prominent lip would either break or become too rapidly blunted. To get over these difficulties, the driller would no doubt reduce his feed by one-half, or to $\frac{1}{200}$ in. per turn, which would mean about half the number of holes drilled in a given time.

This nice accuracy, although absolutely requisite, cannot be produced by hand-grinding; neither can a common drill, having a rough black stem more or less eccentric, be ground accurately, even by aid of a grinding machine with mechanism for holding it. To grind any drill accurately, it must be concentric and perfectly true throughout with the shank, as that part has to be held by the drill-grinding machine. If the drilling is to be done in the most rapid manner—in other words, at the smallest cost,—and if the best class of work is also desired, it seems certain that a twist-drill,

with all the accuracy which can possibly be imparted to it in its manufacture, and with the greatest care employed in the re-sharpening, is the only instrument which can be employed.

About a quarter of a century ago both Sir Joseph Whitworth and the late Mr. Greenwood of Leeds made some twist-drills; but it is to be presumed that a large amount of success was not achieved with them, and for some reason the system was not persevered with. After that period the Manhattan Fire-arms Company in America produced some beautifully-finished twist-drills. Though the workmanship in these was of a superior description, the drills would not endure hardship. It was found that the two lips were too keen in their cutting angles, and that they were too apt to drag themselves into the metal they were cutting, and finally to dig in and jam fast, and twist themselves into fragments. Mr. Morse then took the matter up, and by diminishing by about 50 per cent. the keenness of the cutting lips of twist-drills made a great success of them. He used the grinding line, AB, Fig. 29, Plate 22, and an increasing twist. In such a drill, of the standard length, and before it is worn shorter by grinding, the twist is so rapid towards the lips that the angle they present, or what has been already referred to as the angle of the cutting surface, is very nearly the same as that which the writer had previously established for cutters cutting metals, as in Fig. 21, Plate 21.

If however the angle of twist is made to increase towards the lips, it will of course decrease towards the shank, as in Fig. 29, Plate 22. The shorter the drill is worn, the more obtuse the cutting angle becomes, and the less freedom will it cut with: supposing of course that, when the drill was new, the angle was the most efficient. Suppose this decrease of twist were carried still further by lengthening the drill, a cutting angle of 90° would eventually be arrived at. The old common style of drill usually has such a cutting edge; which is so obtuse as not to cut the metal sweetly, but on the contrary to have more of a tearing action, and thus to put so much torsional strain on the drill that fracture is certain to take place, even if what the writer would now consider a moderate feed was put on by the drilling machine.

It is therefore obviously advantageous to adopt from the first the best cutting angle for all twist-drills, and to preserve this same angle through the whole length of the twisted part, so that, however short the drill may be worn, it always presents the same angle, and that the most efficient which can be obtained. This cutting angle is easy to fix, and becomes an unalterable standard which will give the best attainable results. This has been adopted at the Gresley Works Manchester, and of course applies to both lips.

A common drill may "run," as it is usually termed, and produce a hole which is anything but straight. This means that the point of the drill will run away from the denser parts of the metal it is cutting, and penetrate into the opposite side which is soft and spongy. This is especially the case in castings; where, for instance, a boss may be quite sound on the one side, while the other side, being next to a heavy mass of metal, may be drawn away by the contraction of the mass in cooling, so as to be very soft and porous. In such cases it is perfectly impossible to prevent a common drill from running into the soft side. This sort of imperfect hole is most trying to the fitter or erector; and if it has to be tapped, to receive a screwed bolt or stud, is most destructive to steel taps. The taps are very liable to be broken, and an immense loss of time may also take place in attempting to tap the hole square with the planed face. A twist-drill, on the other hand, from its construction, is bound to penetrate truly, and to produce holes which are as perfect as it is possible to make them.

The next important step in twist-drills has been to fix a standard shape and angle of clearance for both lips, which should also give the best attainable result. This angle might be tampered with if the re-grinding were done by hand, and too much or too little clearance might easily be imparted to the drill from want of sufficient knowledge on the part of the workman. If too little clearance, Fig. 30, Plate 22, or in some cases none at all, is given to the drill, the cutting lips then cannot reach the metal, consequently they cannot cut. The self-acting feed of the drilling machine keeps crowding on the feed until either the machine or the drill gives way. Usually it will be the latter.

Again if too much clearance is given, Fig. 31, the keen edges of the lips dig into the metal, and embed themselves there, and of course break off.

Fig. 32, Plate 22, is drawn exaggerated, in order to show the ill effect of grinding one lip of a drill longer than the other. It is found that the centre point P of the drill will be kept, by the pressure of the feed in the direction shown by the arrow, in the centre of the hole which is being drilled. Then there is a long lip and a short one sweeping round. The hole drilled will therefore be in diameter twice the radius of the longer lip R, or larger by the distance D than the size of the drill itself. This is very undesirable. A much graver defect, arising from this incorrect grinding, is that the drill can only penetrate into the metal it is boring at about half the speed it ought to attain if it were accurately ground. For each lip can only take a certain thickness of shaving per revolution; and if this maximum thickness were taken by the two lips they would remain comparatively uninjured. But the portion C of the long lip would have a double cut upon it (the other lip not cutting at all at this outer portion of the conical hole): hence it would not stand such usage, and would either rapidly blunt itself or would break.

The grinding line A B, Fig. 29, Plate 22, was introduced in the United States, to assist the operator in keeping both lips of the drill identically the same. To arrive at this however is more than can be accomplished by hand-grinding, as not less than three points have to be carefully watched, namely:—

1st. That both lips are exactly the same length;

2nd. That both have the same clearance angles;

3rd. That both make the same angle with the centre line on the body of the drill.

If these are not attended to, the drill lips may for instance be both ground so as to converge exactly to the grinding line at the point or centre of the drill, and may still be of such different lengths and angles as to produce very bad results in drilling.

Much ingenuity has been expended on machines for the grinding of the two lips with mechanical accuracy. The one which has been the most successful in the United States has three motions,

ingeniously combined with each other. So many motions however entail complication; and this, added to a system of holding the drill which was not sufficiently reliable, failed to produce the extreme accuracy it is requisite to impart to the two angles.

The grinding line too is found to be more or less a source of weakness. It is therefore advisable to dispense with it if possible; and where a good twist-drill grinding machine is used, the grinding line is seldom or never looked at, and in that case is useless. If it is still desirable to have grinding lines (as in some cases where hand-grinding has to be relied upon), they should be made as faint as possible, and not cut deeply into the thin central part of the drill, so as to weaken it.

A simple and efficient twist-drill grinding machine was so much needed that within the last three years the writer, aided by his firm, has designed one. The twist-drill in this machine has only one motion imparted to it, to produce the two lips of each drill as perfect facsimiles of each other and with the desired amount of clearance. Many of these machines are now at work. That the drills ground by them are accurate is proved by the holes drilled being so nearly the size of the twist-drill itself that in many cases the drill will not afterwards drop vertically through the drilled hole by its own gravity; in other words, the hole is no larger than the drill which has drilled it. It is not generally known that this is the most severe test which can be made of the accuracy of re-grinding, and of the uniformity of all parts of the twist drill.

One of the smallest-sized machines is exhibited. The largest machine grinds drills of 3 in. diam.; and there are intermediate sizes.

The whole of the drilling in many establishments is now done entirely by twist-drills. Since their introduction it is found that the self-acting feed can be increased about 90 per cent.; and in some engineering works the feeds in some machines have been increased by fully 200 per cent., and consequently three holes are now being drilled in the same time that one was originally drilled with the old style of drill and with old machines.

It may be interesting to give a few results out of numerous tests and experiments made with twist-drills.

Many thousands of holes $\frac{1}{2}$ in. diam. and $2\frac{3}{4}$ in. deep have been drilled, by Smith and Coventry's $\frac{1}{2}$-in. twist-drills, at so high a rate of feed that the spindle of the drilling machine could be seen visibly descending and driving the drill before it. The time occupied from the starting of each hole, in a hammered scrap-iron bar, till the drill pierced through it, varied from 1 minute 20 seconds to $1\frac{1}{2}$ minute. The holes drilled were perfectly straight. The speed at which the drill was cutting was nearly 20 ft. per min. in its periphery, and the feed was 100 revolutions per inch of depth drilled.

The drill was lubricated with soap and water, and went clean through the $2\frac{3}{4}$ in. without being withdrawn; and after it had drilled each hole it felt quite cool to the hand, its temperature being about 75°. It is found that 120 to 130 such holes can be drilled before it is advisable to re-sharpen the twist-drill. This ought to be done immediately the drill exhibits the slightest sign of distress. If carefully examined, after this number of holes has been drilled, the prominent cutting parts of the lips, which have removed the metal, will be found very slightly blunted or rounded, to the extent of about $\frac{1}{100}$ inch; and on this length being carefully ground by the machine off the end of the twist-drill, the lips are brought up to perfectly sharp cutting edges again.

The same sized holes, $\frac{1}{2}$ in. diam. and $2\frac{3}{4}$ in. deep, have been drilled through the same hammered scrap iron at the extraordinary speed of $2\frac{3}{4}$ in. deep in one minute and five seconds, the number of revolutions per inch being 75. An average number of 70 holes can be drilled in this case before the drill requires re-sharpening. The writer considers this test to be rather too severe, and prefers the slower speed.

The drills in both cases were driven by a drilling machine in a true-running spindle, having a round taper hole, which also was perfectly true; the taper shank, and the body or twisted part of the drills, also ran perfectly concentric when placed in the spindle, or in a reducer or socket, having a taper end to fit the spindle. When the drills run without any eccentricity, there is no pressure, and next to no friction, on the sides of the flutes; the whole of the pressure and work being taken on the ends of the drills.

Consequently they are not found to wear smaller in diameter at the lip end, and with careful usage they retain their sizes in a wonderful manner. The drills used were carefully sharpened in one of the twist-drill grinders mentioned above.

In London upwards of 3000 holes were drilled $\frac{5}{8}$ in. diam. and $\frac{3}{8}$ in. deep, through steel bars, by one drill without regrinding it. The cutting speed was in this instance too great for cutting steel, being from 18 to 20 ft. per minute; and the result is extraordinary.

Many thousands of holes were drilled $\frac{1}{8}$ in. diameter, through cast iron $\frac{7}{16}$ in. deep, with straight-shank twist-drills gripped by an eccentric chuck in the end of the spindle of a quick-speed drilling machine. The time occupied for each hole was from nine to ten seconds only. Again, $\frac{1}{4}$ in. holes have been drilled through wrought copper, $1\frac{3}{8}$ in. thick, at the speed of one hole in ten seconds.

With special twist-drills, made for piercing hard Bessemer steel, rail holes, $\frac{13}{16}$ in. deep and $\frac{29}{32}$ in. diameter, have been drilled at the rate of one hole in one minute and twenty seconds, in an ordinary drilling machine. Had the machine been stiffer and more powerful, better results could have been obtained. A similar twist-drill, $\frac{29}{32}$ in. diameter, drilled a hard steel rail $\frac{13}{16}$ in. deep in one minute, and another in one minute and ten seconds. Another drill, $\frac{5}{8}$ in. diameter, drilled $\frac{3}{4}$ in. deep in thirty-eight seconds, the circumferential cutting speed being 22 ft. per minute. This speed of cutting rather distressed the drill; a speed of 16 ft. per minute would have been better. The steel rail was specially selected as being one of the hardest of the lot.

MILLING.

The writer considers milling the most important system used in the cutting of metals, and would willingly dwell more upon it if time would permit. He will confine himself however to giving a few particulars as to the time occupied and the finish produced by milling machines, in comparison with the planing machine, the shaping machine, and the slotting machine. It is found practicable, and in most cases it is exceedingly advantageous, to finish (or as it is usually termed to "machine") almost every class of work, such

as is now usually finished by planing, shaping, or slotting machines, in one or other of the numerous kinds of milling machines already in use.

It may not be generally known that in this class of machine milling cutters are being used of diameters ranging from 12 ft., used for heavy engine-work,* down to $\frac{3}{4}$ in. or $\frac{1}{2}$ in., used principally for the intricate work required in sewing machines, small-arms, &c. By the former, the work done is what is known as face-milling: the mill itself is somewhat similar to a large lathe face-plate, and the several cutting portions are steel tools inserted into it and firmly secured by a series of set-screws or keys. On the other hand, the milling cutters of the small sizes, from $\frac{1}{2}$ in. up to about 8 in. diameter, are made from solid blocks of cast steel, or blanks, as shown in Figs. 33 to 38, Plate 23.

The term "milling" is more generally understood in the United States than in this country. It means the cutting of metals by aid of serrated revolving cutters, each having a number of cutting teeth. Milling cutters have been used in this country for many years, but until recently with only a limited amount of success, owing to the expense and difficulty of producing their cutting edges and keeping them in order. This was next to impossible before the introduction of a machine, with a small emery-wheel and compound slides, &c., for carrying the milling cutter whilst being re-sharpened. Hence in the old system of milling, which did not permit of the re-sharpening of the hard teeth, the results were, that after much expense and time had been bestowed on a cutter (including a quantity of hand-labour spent upon it while in its unhardened state), the whole was as it were upset by the process of tempering; the accuracy which had previously been imparted to it being usually quite destroyed by the action of the fire and sudden cooling. In some cases the cutter would be found slightly warped or twisted; in others it would be oval or eccentric; and most frequently, when set to work

* These large machines were designed by the late Mr. David Elder and by Mr. Alexander C. Kirk, and are in use at Messrs. John Elder and Co.'s Works, Glasgow.

on a truly-running mandril in the milling machine, not more than one-third of the number of its teeth were found to be cutting at all, the others not coming in contact with the work. This really meant that not more than one-third of the proper feed per revolution could be applied, and not more than one-third of the proper work produced. Nor was this the only drawback: the quality of the workmanship produced by such a milling cutter was not of the best, and deteriorated hourly from blunting and wear. Such a cutter would probably not work for more than two whole days before it would require to be again softened by being heated red-hot and allowed to cool gradually. The expensive and unreliable process of re-sharpening by hand-filing had to be gone through once more; then the re-tempering, which caused the cutter again to become warped, swelled, or eccentric; and each time it was subjected to the heat of the fire, it ran the risk of being destroyed by cracking when plunged into the cold bath.

It is necessary now to describe the modern system of making and maintaining the improved milling cutters. A cast-steel forging, or blank as it is usually styled, is bored, and then turned to its proper shape in a lathe. The teeth are then machined out of the solid to their required forms, in a universal milling or other machine. This work is so accurately produced, direct from the machine, that no costly hand-labour need be expended upon the milled cutter, which is taken direct from the milling machine to the hardening furnace, and tempered. The hole in the centre of the cutter is then carefully ground out to standard size, so that it may fit accurately and without shake on the mandrils both of the grinding machine and of its own milling machine.

The cutter or mill C, Fig. 39, Plate 23, is now placed on the mandril M of the small cutter-grinding machine; the mandril itself is adjusted vertically and horizontally by ordinary slides, and by means of a worm W and worm-wheel B, to its required angular position; and each tooth is ground or re-sharpened by passing it once rapidly forward and backward under the small revolving emery-wheel H. The mandril fits easily into the cutter which is being ground, so that the latter may be readily turned round by the thumb and finger of the operator.

The exact mode of setting such cutters is as follows:—The clearance angle L J K on each tooth is obtained and maintained by the emery-wheel H, of which a specimen is exhibited. The clearance is obtained by adjusting the centre I of the emery-wheel H a short distance horizontally behind the vertical line D M through the centre of the milling-cutter. The shorter this distance D I, the less the amount of the clearance imparted to each tooth of the milling cutter C. The upper dotted line J L is a tangent to the circumference of the milling-cutter, drawn from the point of contact J; and the lower dotted line J K is a tangent to the emery-wheel from the same point. The angle formed by these two lines is the angle of clearance.

Each tooth is held in its correct position by means of a stop S, while the milling cutter is rapidly traversed once forward and backward under the emery-wheel. As will be seen by the arrows, the tendency of the emery-wheel is to keep the cutting edge which is being ground close up against the stop S. There is no more difficulty in grinding spiral cutting edges than straight ones; and face and conical cutters can also be ground correctly, and with the same amount of ease.

Milling cutters are made of the required forms to suit the various shapes they are intended to produce; and all the ordinary forms can be used in any milling machine either of the horizontal or vertical class.

The face-milling cutters, Figs. 40 and 41, Plate 23, are of disc form, and are among the most useful. They are constructed to cut on one face and on the periphery; and they produce very perfect finish, especially on cast-iron. This form is also very useful for stepped work, which, even when not of the simplest form, can be readily and reliably finished to standard breadths and depths: so that the pieces may be interchangeable, and fit together without the slightest shake or play, just as they leave the machine, and without any hand-labour bestowed on them.

Another ordinary and very useful form is the cylindrical cutter, Fig. 42, Plate 23, with teeth cut spirally over its circumference. This is largely employed for cutting flat, vertical, or horizontal surfaces, for finishing concave and convex curves, and for complicated forms made

up of straight lines and curves. With this spiral arrangement of the teeth, and with reliable means of re-grinding or re-sharpening them, very high-class machine-work can be produced. Some experiments have been made by cutting a spiral groove or thread into the outer surface of one of this class of mills, and thus reducing the aggregate length of its cutting surface. The results appear to be practically as follows:—If half the length of cutting edges are dispensed with, only about half the maximum feed per revolution of the cutter can be applied by the machine; if three-quarters of the length of the cutting-lips are left intact, three-quarters only of the aggregate feed can be used; and so on in the same proportion.

Other mills again are made in the form of small circular saws, varying from $\frac{1}{4}$ in. to $1\frac{1}{2}$ in. or more in thickness. The teeth in some of these are simply cut around the circumference; others have these teeth extending some distance down each side, their edges radiating from the centre of the mill, as in Figs. 43 to 45, Plate 23. Towards the centre they are reduced in thickness so as to clear themselves. These cutters are useful for a very great variety of work; for instance the cutting of key-ways, parting off or cutting through pieces of metal, and making parallel slots of various widths, for the broader of which two or more cutters may be used side by side.

Conical and angular milling-cutters, Figs. 33 to 38, Plate 23, are much employed for a great variety of work, such as the cutting of rymers, the making of milling cutters themselves, bevelling, cutting the serrated part of hand- and thumb-screws, nuts, &c. Figs. 34 to 37 are edge views of four of these cutters; Fig. 33 is a face view, and Fig. 38 a section of one of them.

Any complex forms, such as the spaces between the teeth of spur, mitre, and other wheels, can be machined by using what are known as the patent cutters, which can be re-sharpened as often as required by simply grinding the face of each tooth. They are so constructed that, however often they are re-ground, they never lose their original curved forms, and always produce the same depths of cut. One of these cutters, for instance, will cut the same standard shapes of teeth in a spur-wheel, after it has been used for years, as it did the first day it was started.

There is risk of fracture in making large milling-cutters out of one solid cast-steel blank, the principal difficulty being in the tempering. In practice it is found that if they are required of larger diameter than about 8 ins. they are better made of wrought-iron or mild-steel discs, with hardened cast-steel teeth so securely fitted into them that they do not require to be removed. The cutting edges can then be re-sharpened in their own places, as in the case of the ordinary milling-cutters; thus ensuring that each shall have the same angle of cutting and clearance, run perfectly concentric, and therefore do a maximum amount of cutting in a given time. It must however be borne in mind that the smaller the diameter of the milling-cutter, the better finish it will produce; and cutters of large diameters should only be used to reach into depths where one of smaller diameter could not, or to do the heavier classes of work. Again, the smaller the cutter, the less does it cost to make and maintain.

The writer has not had an opportunity of actually testing the relative amounts of engine power required for driving milling machines; but, as far as he can judge from ordinary practice in doing ordinary work, he has not perceived that any more power is required to remove a given weight of shavings than that required for a lathe, planing machine, or shaping machine, with efficient cutting tools in each case.

The cutting speed which can be employed in milling is much greater than that which can be used in any of the ordinary operations of turning in the lathe, or of planing, shaping, or slotting. A milling cutter, with a plentiful supply of oil, or soap and water, can be run at from 80 to 100 ft. per minute when cutting wrought iron. The same metal can only be turned in a lathe, with a tool-holder having a good cutter, at the rate of 30 ft. per minute, or at about one-third the speed of milling. Again, a milling cutter will cut cast steel at the rate of 25 to 30 ft. per minute.

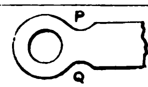
The increased cutting speed is due to the fact that a milling cutter, having some thirty cutting points, has rarely more than three of these cutting at the same time. Each cutting point therefore is only in contact with the metal during one-tenth of each

revolution. Thus, if we suppose it is cutting for one second, it is out of contact, and therefore cooling, for the succeeding nine seconds, before it has made a complete revolution and commences to cut again. On the other hand, a turning tool while cutting is constantly in contact with the metal; and there is no time for it to cool down and lose the heat imparted to it by the cutting. Hence, if the cutting speed exceeds 30 ft. per minute, so much heat will be produced that the temper will be drawn from the tool. The same difficulty to a great extent applies to the cutting tools in planing, shaping, and slotting machines. The speed of cutting is governed also by the thickness of the shaving, and by the hardness and tenacity of the metal which is being cut: for instance, in cutting mild steel, with a traverse of $\frac{3}{8}$ in. per revolution or stroke, and with a shaving about $\frac{5}{8}$ in. thick, the speed of cutting must be reduced to about 8 ft. per minute. A good average cutting speed for wrought or cast iron is 20 ft. per minute, whether for the lathe, planing, shaping, or slotting machine.

COMPARISONS OF TIME OCCUPIED IN ROUGHING-OUT

Class of Work.	Kind of Metal.	Size and number of Surfaces.	Shape of Surface machined.	Milling Machine.
Lower part of 4½" pedestal . . .	Cast iron	18" × 6"	Flat under-surface	One cut over, 7¾ minutes
Ditto	Cast iron	18" × 6"	Ditto	2 cuts, 16 min.
Ditto	Cast iron	Two 6" × $\frac{9}{16}$" Two 6" × ½"	Vertical surfaces Horizontal surfaces	4½ minutes
Ditto	Cast iron	Two 2¾" diam. each	The upper surfaces of two bosses	2 minutes each
Cap for ditto . .	Cast iron	One 1⅝ diam. Two 2½ "	Horizontal surface Ditto	1½ minute 3 " each
Ditto	Cast iron	Two 6" × $\frac{9}{16}$" Two 6" × ½"	Horizontal surface Vertical surface	4½ minutes
Plate	Wrought iron	6¼" × 3"	One flat surface	Finished in 6 minutes at one cut
End of Flat Joint, as in Fig. A, opposite . . .	Wrought iron	One convex & two concave surfaces	. . . .	18 minutes roughing & finishing.
Plate	Mild steel	2¾" × 6"	One flat surface	5½ minutes finished at one cut
Surfaces of Pawl, as in Fig. B, opposite . . .	Mild steel	Three curves	. . . .	18 minutes roughing & finishing on curves
End of a reversing lever	Mild steel	. . . . .	Two flat surfaces & 2 curves	17 minutes

AND FINISHING METAL SURFACES IN MACHINE TOOLS.

Time occupied by			Remarks.
Planing. Machine	Shaping Machine.	Slotting Machine.	
One cut over, 11¼ minutes			
2 cuts, 22 min.			
. . . .	38 minutes . .	. . . .	In the milling machine all these four surfaces were roughed out and finished at one pass, whereas four passes are needed in the shaping machine.
. . . .	3½ minutes		
. . . .	. . . .	. . . .	Cannot be done except in a milling machine.
. . . .	38 minutes		
. . . .	8 mins. roughing 3 „ finishing 11 „ total	. . . .	The milled surface quite as good as the shaped.
. . . .	. . . .	44 minutes roughing and finishing	Fig. A. Scale $\frac{1}{10}$. 
. . . .	13 mins. roughing 7 „ finishing 20 „ total		
. . . .	. . . .	36 minutes roughing and finishing curves	Fig. B. Scale $\frac{1}{10}$. 

Abstract of Discussion on Modes of Cutting Metals.

Mr. Ford Smith exhibited and explained many of the tools referred to during the reading of the paper; also specimens of work done by various tools; and two machines, one for grinding milling cutters, and the other for grinding twist-drills. He also referred to the accompanying Table, page 250, which gave the speeds at which some of the work exhibited had been produced. The experiments described in this Table had been made principally to test the speed of milling against that of shaping, planing, slotting, or turning. For instance, the lower portions of two pedestals had been one of them shaped, and the other milled with a milling cutter. The time occupied on the former had been 11¼ mins. for each surface once passed over, and on the latter 8 mins., the area being 18 in. by 6 in. The other experiments were of a similar character. In another case, of two wrought-iron forgings for the ends of flat joints, shown at Fig. A in the Table, one was given to a man at the milling machine, and the other to one of the best slotters in the works. These men knew that they were working against each other, and did their best; and the time came out, with the milling machine 18 mins., and with the shaping machine 44 mins., which was a great disparity. One reason was that the latter required three settings, as almost all such convex and concave curves did; first it had to be set so as to finish into the corner P, then into the corner Q, and then a third setting was needed for going round the outside convex surface. When a milling cutter large enough in diameter to form the corners could be used, it could be set to machine the required breadth, and, by once feeding it round the end of the joint, finish it. Again, facsimiles of the pedestals referred to at the top of the Table—which had been produced in large quantities — were all machined so absolutely to standard breadths and depths, direct from the milling machine, that, for instance, any cap would fit any lower piece with such perfect precision as to be quite free from shake, and thus require no fitter's hand-labour to be spent upon it. In other words the

lower pieces and the caps were interchangeable; and as the under surface of each pedestal had also been milled over—the milling system having been employed throughout—the height of the centre of each pedestal from its base was ensured correct to one standard uniform measurement. Such accurate results could not possibly be produced in the same short space of time by any other means. Reference to the Table, page 250, showed $4\frac{1}{2}$ mins. for milling against 38 mins. for shaping, for the parts of each cap and each lower piece, where they fitted together.

Mr. J. H. Wicksteed said the question of drills seemed to him to be not entirely worked out in pp. 236–239. There was part of an ordinary drill, close to the point P, Fig. 26, Plate 22, which did not cut at all. If it was looked at from below, as in Fig. 28, there was an oblique line IJ, forming the connection of the two ground edges of the drill. That line IJ was not cutting; it merely ran round and rubbed; and that was the part which required all the force on the top of the drill to drive it into the metal. However much the cutting angle of the drill might be improved at the edges PM, PN, Fig. 26, that would not improve the connecting line IJ, Fig. 28; hence in any material, if you had a small core-hole to start with, you could employ at once a feed four times as rapid as you could employ when drilling through a solid piece. However quickly the drill was rotated, it did not give too high a cutting speed at the point P, Fig. 26; it was too near the centre for that. Therefore he was not quite sure whether Mr. Ford Smith's system repaid him for his trouble, and for the extreme accuracy required in arranging the cuts; because it was not for the sake of the cutting edges, even if they were not particularly good, that you needed so low a rate of downward feed as one hundred cuts to the inch; but it was for the sake of preserving the point, and giving it time to force itself into the metal, that you were obliged to employ fine feeds.

He was a little surprised at Mr. Smith's proportion of feed to number of revolutions. He made the drills revolve with a circumferential speed of about 20 ft. per minute, and gave them about 100 revolutions to the inch of downward traverse. He himself

should have used 200 revolutions to the inch of downward traverse, and a cutting speed of 40 ft. per minute, in cases where water could be used.

With regard to the rests, he would ask members to look at the swivel tool-holder, Figs. 1 and 3, Plate 19, and compare it with an ordinary slide-rest, as in Fig. 12A, Plate 20. In the latter the whole of the tool was bearing on the rest, and that was down upon the bed of the lathe, and held to it by the V's. It was quite clear that the tool was supported under its heel, and could not spring away from the cut. That was the right position for taking a heavy cut without jar. Not only was the tool supported under the heel, but the rest was supported by the lathe bed, and the point of pressure was not outside the point of support; so that there was no tipping action against the inverted V. He did not see that the arrangement of movable tools lent itself so well to heavy cuts, although it facilitated getting a thoroughly good edge, and was first-rate for giving the high finishes which Mr. Smith produced. There were also a great many instances where you must have an overhang, whether you liked it or not, for instance, with a parting tool; and there Mr. Smith's form of tool-holder was right, and convenient. Thus the parting tool, Fig. 9, Plate 20, was in a very good position, because the spring that inevitably took place when the tool projected beyond the support, took place in the direction indicated by the dotted arc PQ, with the centre C, and tended to relieve the tool out of its work, instead of making it dig into it. Again, if you were roughing with a tool in a strong planing machine, and could bring the planing-machine box down to the position shown in Fig. 9A, Plate 20, you were in the best position for taking a heavy cut. But if you were obliged, for the sake of a parting cut, to make the tool project below the tool-box, that tool should be of the form shown in Fig. 9; otherwise, since the spring of the tool would come from C, the point of the tool would gather into the work, as shown in Fig. 9B. But with Mr. Smith's tool, having thrown the tool back to the position shown, the point of the tool relieved itself; and you could get on a great deal better for that reason. He had no doubt that this was the explanation why the composite tool in the particular experiment given first in the

Table, page 250, got on nearly twice as well as an ordinary solid tool, which was probably made as indicated in Fig. 9B.

Mr. Arthur Paget wished to ask Mr. Ford Smith whether there was any means at present in use of obviating the one defect which he had constantly found to exist in twist drills. It was very analogous to the defect pointed out by Mr. Wicksteed in the old form of flat drill—namely that the front part of the drill, on the line IJ as shown by Mr. Wicksteed, Fig. 28, Plate 22, did not *cut* the metal at all, but was forced into it by a sort of bruising or crushing action; but he had imagined that nobody but the traditional village blacksmith now made flat drills according to the form shown by Mr. Wicksteed. Flat drills should always be made to the shape shown in Figs. 27A and 28A, Plate 22, thick at the shoulders of the drill and coming to a thin edge at the point. The drills in his works, for the last twenty years, had been made to that shape; and then there was very little of that forcing the point into the metal which Mr. Wicksteed had spoken of. The only difficulty that he had noted in twist-drills was that there was in these drills no means of reducing the blunt point (or line IJ, Fig. 28, Plate 22), between the two grooves, which did not cut at all, but merely squeezed itself into the metal. There must be proportionately much more work concentrated on that little spot than on all the rest of the metal being drilled. He should be glad if Mr. Ford Smith could tell them of some means of obviating that defect. It was of more importance in small drills than in large ones; because that blunt point (or line IJ) in the smaller drills bore a much larger proportion to the whole area.

Mr. William Anderson wished to compare the finish of the two specimens of flat joint-ends, Fig. A in the Table, p. 251, one made with a milling cutter, the other in a shaping machine. He could tell by feeling, with his eyes shut, which was which. The one that was done by a milling cutter was all in ridges, and the one done by the shaping machine was quite true and smooth. The author had been comparing the cost of the two processes; but such comparison could not fairly be made, because the quality of the work

was so different. If appearance were all that was wanted, the comparison might hold; but for real quality of work, necessary for instance if the joint ends were meant to work against a bearing, the shaping machine had alone done satisfactory work.

Mr. Daniel Longworth said the author stated, p. 227, that he had adopted one cutting angle both for cast and for wrought iron, simply for the purpose of having uniformity. But all writers on the subject, and those who had experimented in the workshop, had come to the conclusion that two angles were really necessary; and sometimes even more, according to the hardness of the material. He wished to ask Mr. Smith what angle he had finally adopted, as in his former paper he had taken 50° for wrought iron and 60° for cast iron. In the paper reference was made to broad cutting; and he should have thought that the angles shown in Figs. 1 and 3 would not do very well for broad cutting.

He thought Mr. Smith deserved credit for again drawing the attention of engineers to the great importance of having uniformity if possible in their workshop tools. At the same time the author perhaps gave more credit to the tool-holder than was really due to it. The success obtained, p. 234, was rather due to the accuracy of the cutting edge; for in comparing work done by the tool-holder with work done by one of his workmen with an ordinary tool, Mr. Smith's superior knowledge of the best cutting edge in that particular case had been put against that of the workman. No doubt, if the one tool had had the same cutting edge as the other, the result would have been precisely the same.

Another question he wished to ask was whether Mr. Smith had succeeded in dispensing with the rose bit; that is, in making holes, by the drill alone, to fit accurately a pin turned to gauge. If he had done that, he had certainly made a great step in advance; because in ordinary work, where a pin was required to fit a hole accurately, it was necessary to use a rose bit, even after the hole had been drilled by a twist-drill ground carefully by hand.

As to milling cutters, Mr. Smith was right in stating that the introduction of the little emery-wheel and its attachments for

sharpening the cutters had been one of the greatest improvements made. Milling machines had been tried, to his own knowledge, fifteen years ago for grooving steel; and they were abandoned after great expense had been gone to, because of the difficulty and cost of sharpening and maintaining the cutters. Mr. Smith had not shown any samples of brass-work finished by milling. Milling had been tried from time to time for brass, but had never succeeded to any extent, because of the difficulty met with in the grooves getting clogged up, and because the ordinary single fly-cutter or tool was durable and accurate enough for most purposes. He should like to ask therefore if the author had made any improvements in milling brass. For cutting cast iron to standard forms the milling cutter was the best tool to use; he knew of cases where small milling cutters were successfully employed on cast iron at a speed of 250 feet per minute.

Mr. JEREMIAH HEAD thought they had scarcely yet complimented Mr. Smith sufficiently on his valuable paper. Papers of that kind, even although they might contain nothing absolutely new, yet if carefully worked out, as Mr. Smith's had been, certainly did an enormous amount of good, by spreading among the whole body of the members information which, so far, might have been confined to a few. But Mr. Ford Smith had done more than that. He had concentrated his attention on a department of mechanical engineering which was of extreme importance, although it had hitherto attracted but little attention. That department included the form and maintenance of cutting tools, the work they would do in a given time, and so forth. He noticed that Mr. Smith had not said anything about the kind of steel which he used or recommended for tools; but he gathered from the general tone of his remarks that his desire was to avoid smith work as much as possible—to take a piece of steel which was originally of the proper hardness and temper, and, if possible, to use it up simply by grinding it gradually away. Now it was well known that there were certain alloys of iron and other elementary substances forming steels, such as chromium steel, titanic steel, &c., with peculiar characteristics. There was also "Mushet's special steel,"

which was said to be more enduring than ordinary cast-steel; and it would be interesting to know whether Mr. Smith's arrangements necessitated having steels of these or any other special kinds.

With regard to the term "milling," he remembered many years ago that it was used simply for a little tool that made a serrated edge on small nuts in brass work. He presumed that the carrying on of the name to a kind of work, which was entirely different, had come from the tools used in the two processes somewhat resembling one another. The paper seemed to show that milling in its new sense had been wonderfully perfected in recent years, and for many operations, in engineering work, was destined to supersede ordinary cutting tools.

Mr. JOHN FIELDING agreed with Mr. Head in thanking the author for the able manner in which he had brought his paper before them; but he should like to ask him some questions about the maximum speed he had been able to obtain in cutting with his tools. As bearing upon that question, he had brought with him two cast-iron tools having chilled points. While he did not assert that the use of cast iron for tools was new (it was really very old), he should like to ask why it had not come more generally into use. The tools were simply copies of an ordinary forged tool, cast with a piece of iron in the mould to chill the face; and with these tools he had been able to turn cast iron, wrought iron, and gun metal at speeds from 50 to 100 per cent. greater than with the best special steel. His firm had tried Mushet steel, as good as they could get it; but with cast-iron tools they had been able to do from 50 to 100 per cent. more work. It had struck him, in hearing Mr. Smith speak of broad-finishing cuts, that cast-iron chilled tools were applicable for such work, because you could thus get a heavy tool at a minimum cost. A broad tool necessarily meant a heavy tool, in order to get sufficient rigidity (to which Mr. Smith rightly attached great importance): and the cutting edge in chilled iron being extremely hard, it would stand its work very well, as was shown by the fact that cast iron was used in turning chilled rolls. While such tools could not compare with Mr. Smith's as a complete system, he thought they afforded some

advantages in heavy cutting. They were able to furnish the correct angles at a moderate cost, about 1*d*. per pound, whereas the cost of steel was twelve or fifteen times that amount.

With regard to milling machinery, the value of that part of the paper would have been vastly enhanced if it had shown the different forms of machines used, both with vertical and with horizontal spindles, and had described how they would replace slotting, planing, and shaping machines.

Mr. John Robinson joined with Mr. Head in thanking Mr. Ford Smith for bringing before them the means of arriving at correct cutting angles. He had no doubt that Mr. Smith would remember the "revolving cutters," as they were then called, which were formerly in use at the Atlas Works in Manchester. All the surfaces of four and six-sided nuts were dressed by that process, now improperly called milling. Another operation which at that time they carried out by the same means was that in cranked axles, after being forged quite solid, the two cranks were then cut out with the milling tools. Afterwards, he scarcely knew why, slotting tools were used for the purpose; and then the pieces left were taken out by means of a drill. On the whole he believed the milling process was the most economical; but the difficulty (which Mr. Smith seemed to have got over by the methods he had adopted) had been to keep the cutters in sufficiently good order. They had formerly no such thing as the grinders, which had been invented of late years; and the process of sharpening up and hardening was very tedious and very expensive.

With reference to some of the forms of cutters—for instance Fig. 8 and Fig. 10, Plate 19—he should like to ask whether the cutter in Fig. 10 had not been forged to the form which it possessed, in order to take the under cut. The cutter in Fig. 8, although it was "necked" in, as they would say in the North, seemed probably to be worked by simple grinding from an ordinary form of tool steel. With reference to such forms as in Fig. 9, Plate 20, which was a planing-machine tool, it seemed to him that the number of joints through which the stress on the tool had to pass, before it met

with the ultimate resistance of the cross-head, was considerable, and likely to create jarring. He admitted that all the other joints, except those on the tool itself, existed before, and were necessary in order to get the requisite motions; but now there were two or three other surfaces of division, which would have to be taken into account. He should like to ask Mr. Ford Smith whether in practice he found it difficult to keep those surfaces so tightly bolted up as to prevent a jar in the tool, when it was cutting a surface in the way shown in Fig. 9. The same observation applied perhaps to the swivelling tool-holder, Fig. 3, Plate 19. It was exceedingly ingenious; still every one knew that such implements, when screwed up by workmen who were not so careful as they should be, were liable to get out of order. The forms of steel used for the several cutters represented in the drawings showed that Mr. Smith had taken all possible pains to produce nicety of work; and he could not but speak highly of the desire shown to keep the tools out of the hands of the smith, not only because of the expense of forging, but also to preserve the original temper of the steel, when that temper was well adapted to the object in view.

The mode of grinding in Fig. 39, Plate 23, was exceedingly ingenious, and showed how inexpensive the actual processes were, if only you had money to buy the tools first, and men to work them well afterwards; because, after all, it was a kind of machine that could not advantageously be put into a shop, unless it was carefully looked after by trustworthy men. The whole system was one which required organisation, a point in which Englishmen often fell behind their continental brethren. Mr. Smith had done wisely to arrange the system, and bring it to them ready cut and dried; and the only thing to be done was to persuade people to take it up and follow it out.

With regard to cast-iron tools, what seemed to him to be a disadvantage in them was, that they could not be ground up very frequently. It was easy to make a casting from a pattern, but the cutting angle would soon be ground off, and then the whole mass of cast iron was thrown away, in regard to its usefulness as a tool. But in the form of tool which Mr. Smith had shown, the

tool could be worked up until it was too short to be held in a holder; while nine-tenths of the cast-iron tool had to be thrown away.

Mr. FIELDING asked leave to make a remark with reference to the last point that Mr. Robinson had mentioned. By chilling $\frac{3}{8}$ in. deep, the tool would wear for a very long time; and when it was worn away, the cost of melting it up, and running it into a mould again, was much less than the cost of forging a fresh tool.

Mr. W. W. HULSE thought they must all admire the tenacity with which Mr. Smith and his firm adhered to the question of tool-holders. That subject was one in reference to which there had been a good deal of experience at the works of Messrs. Whitworth & Co. From time to time it was resuscitated, but it always had to be as it were flogged into activity. The tool-holder, no doubt, was a valuable thing, but it was very limited in application to general workshop practice. One reason he supposed was that engineers looked every day more and more not merely to polishing the outside of a piece of metal with a machine tool, but to doing a large portion of the work which was formerly left to the forge. He had with him some cuttings which were taken from a lathe recently made by his firm; these showed what description of cutting was expected of a machine tool in the present day; and he would ask any one to say whether any form of independent tool-holder could support a cutting tool that would deliver cuttings of that kind. The cuttings were just as they came from the lathe, off a piece of good tough steel, 28 in. in diameter, cut at the rate of 6 feet per minute circumferential speed; they were about $1\frac{1}{2}$ in. deep by $\frac{1}{4}$ in. thick, the traverse being $\frac{1}{4}$ in. in each revolution. That was what the modern lathe was expected to do, and no tool-holder had been introduced that could do it (unless the slide-rest might be called a tool-holder), nor anything but a solid bar of steel, $2\frac{1}{2}$ or 3 inches square, absorbing the heat as it was generated. The twist-drill no doubt was also a very excellent thing; and Mr. Smith's firm deserved credit for the tenacity with which they kept those small tools in view; but he had recently had sent to him some samples of cuttings from a new drilling machine,

just made, for dealing with the couplings of propellers, in which the bolt holes were to be drilled out of the solid, each at one operation. The cuttings came from a flat drill, 3 in. diameter, at the rate of $\frac{1}{60}$ in. per revolution, and they were equal to if not greater than anything that would come from a twist-drill. No doubt one advantage of the twist-drill was the maintenance of shape and size; but the readiness with which the workman could deal with a flat drill would, he was afraid, keep it always in the workshop. That milling or (speaking more correctly) circular cutting machines would displace planing, shaping, and slotting machines, he did not believe. Circular cutters certainly had their uses, notably for articles of which a large number were required; but the bar tool was ready at all times for any change of form. The planing, shaping, and slotting machines, with bar tools, could undoubtedly produce truer planes than circular cutting machines, unless in the latter case each tooth of the revolving cutter acted throughout its whole length upon the surface to be planed, or unless all the teeth revolved in one plane, which in practice could not be ensured after hardening. Nevertheless circular cutting machines, if properly arranged so as always to keep a firm hold on the revolving cutters, were most useful additions to engineering workshops, especially for shaping frequently repeated articles and forms; and for such work, where the configuration was principally to be considered, the circular cutting machine was undoubtedly most expeditious and sufficiently accurate.

Mr. J. HAWTHORN KITSON said that for some time he had been working with revolving cutters of considerable dimensions; and he had put on the table two specimens of the kind of work they were doing. One was a cross-head, the jaws of which were cut out of the solid with two cuts of a revolving cutter. It was done at a very considerable speed, and after the first cut there was only about $\frac{1}{8}$ in. left for the second cut. It would be seen that the finish was as good as could be desired. The other specimen was a large eccentric joint. They had previously tried punching out the middle of the joint under the hammer; but they found that with a set of cutters,

cutting out the middle, and finishing the two outside faces at the same time, they could work as rapidly cutting out of the solid, and it was decidedly cheaper. The finish was not perfect; but a file, or something like it, had to be applied to all such work for its final adjustment, as the work altered its shape when cut out; and the cutter gave what they considered a sufficiently good workshop finish. The work had also been milled all over outside.

The paper stated, p. 247, that a cylindrical cutter with a spiral groove dividing the teeth would not do as much work as one with solid teeth. But he had found that for roughing work, they could take double as great a cut, either in depth only, or in depth and traverse combined, with the grooved cutter, Fig. 46, Plate 24, as they could with the plain cutter. In finishing work, they required to have the solid cutter. On some of the foreign railways milling had been studied very minutely and scientifically. Figs. 47 to 49, Plate 24, showed a French cutter sent to him from the Paris and Lyons Railway. It was found that the angle of the teeth was a question of very great importance; and after careful study the conclusion arrived at was that the pitch should be six times the diameter. The tool did very beautiful work, but only at a quarter of the speed at which the work could be done with the grooved cutters, Fig. 46. The latter broke off pieces $\frac{1}{4}$ or $\frac{3}{8}$ in. wide, instead of long thin shavings, and the cutters seemed to relieve themselves in that way.

The PRESIDENT said, before asking Mr. Smith to reply, he would say a few words. He could confirm all that Mr. Smith had said, and even more, with regard to the advantage of milling. First, as to the endurance of the tool. If the tool were held firmly, without vibration, it would last an extraordinary length of time. The inequalities that were noticed in milling were not due to the tool but to the machine, the parts not being sufficiently strong and rigid to prevent vibration. A remark had been made by Mr. Anderson with regard to two pieces he held in his hand, that he could tell with his eyes shut which was which. In that case probably the spindle which held the cutter was too weak, or else the rest in which it was held vibrated, producing the ridges which were felt by the

touch; but, where the tool was firmly held, he had seen milling turn out work as accurately as slotting or planing could do. He believed that there was a great future for milling. With regard to the question of endurance, he had one tool which had been in constant use for eighteen months, with a little grinding up occasionally; and it still did its work admirably. Of course they were expensive tools to get up; and great care should be taken to get a good steel, and to anneal it properly. He could confirm Mr. Kitson's statement with regard to the grooving of cylindrical milling tools. He found that for rough cutting, the groove certainly did enable them to take a heavier cut than they could take with the plain tool. A question had been asked by Mr. Longworth as to the milling of brass. His experience was that tools such as were shown in the drawings, which were for cast-iron or wrought-iron, would not answer for brass; a greater pitch between the teeth and a higher speed were necessary for brass.

He thought Mr. Ford Smith's perseverance in carrying out all his arrangements deserved great credit. Some years ago, when endeavouring to introduce the system, he himself had found that, in a shop where there was a great variety of work, heavy and light, they were not able to carry it out thoroughly; but they still used a good many of the tools for certain work. For really heavy work the system did not answer so well, and chiefly for this reason, that in very heavy work it was absolutely necessary to have a large, heavy tool, and to have the point supported immediately underneath by the rest—in fact to make the whole as rigid as possible. It was also necessary to have plenty of steel in the tool, to carry off the heat induced by a heavy cut. In the tools described in the paper, where there was necessarily an overhang, and where the tool-holder was composed of several parts, there was not sufficient rigidity to take off a tearing cut.

Mention had been made of Mushet steel; and for some purposes that steel was unsurpassed. It was a very peculiar metal. It had to be worked up to a good heat and simply allowed to cool in the open, and it must not be tempered or used with water. It did not do its work properly until it had got fairly hot. In one machine, used for turning up hydraulic rams, with three tools—two rough cuts and a

finishing cut—they had turned with one set of tools eleven rams, 10 in. diam. and 12 ft. long; they never touched the tools once, putting in ram after ram, and the last was as good as the first. But that machine gripped the work like a bull-dog, so that there was no vibration between the tool and the work.

With regard to drills, he did not look upon the twist-drill by any means as a universal tool. For some purposes the flat drill—if properly made, with the same care and precision as were expended in making twist-drills—was superior. Hitherto one of the great advantages of the twist-drill had been that so much care and pains had been expended in getting it up; but he had found that, using flat drills, and taking the same amount of care to ensure the sides being parallel and the angles cut even, and also pointing the edge truly so as to do away with the blunt nose, the drill would work freely, and the shavings come off even better than from the twist-drill. In drilling through cast-steel, about 11 in. deep, he had seen shavings coming out, on either side of the drill, from 10 to 12 in. long, or even more; and he did not think that a twist-drill would enable them to accomplish that. There was of course this difference between the plain drill and the twist-drill, that in forming the latter you sacrificed a great quantity of material in cutting out the groove; and it was of course a much more expensive tool to get up. In the flat drill there was very little waste of material, and it could be drawn down when it got too short; whereas when a twist-drill got too short, it became valueless. In going through bad castings however, there was no doubt the twist-drill would make a straighter hole.

Mr. Paget asked leave to put a question as to the objection made to the tool-holder, namely the want of a mass of metal to take away the heat. A former member of the Institution, the late Colonel Clay of Liverpool, had produced some years ago before the Institution (Proceedings 1872, p. 288) a tool with a hole bored through it, so that water could be made to pass along the inside to absorb the heat. He wished to ask Mr. Ford Smith whether he had tried that plan in connection with his tool holder.

The PRESIDENT said he had found that the less one dealt with water the better. If steel of sufficient size were used, very little water was required; in fact, cutting steel with steel, water was not wanted at all. With regard to cast-iron tools, he might say that he had tried them only for castings which were so exceedingly hard that steel would not touch them. But, for the reasons given by Mr. Robinson, he did not think they were universally applicable.

Mr. THOMAS R. CRAMPTON asked permission to say a word upon some experiments he had made to show the bad effects of jarring, when using revolving disc-cutters for shaving off chalk or stone. He found that, when the cutters and cutter-head were too light, the material was simply disintegrated; but when the whole was firm and solid, shavings were cut off quite smooth even in sandstone, which was so easily broken when thin. The shavings on being cut ran up the revolving cutters like ribbons. The firmness of the tool also reduced considerably the power required to do the work.

Mr. W. FORD SMITH in reply said that Mr. Wicksteed had alluded to the thickness of the point of the drill being an objection, and Mr. Paget had also referred to the same subject. The difficulty of boring with a large drill which had a thick point was by many engineers overcome by first drilling a small leading hole, and afterwards opening it out to the required size by using a large drill, the point of which, entering into the small hole, had no cutting to perform. There were two objections to that plan; the first being that the point of the larger drill, not having any metal before it to support and steady it, was free to run eccentrically, oscillate transversely, and revolve with a series of jerks, thus producing a badly finished hole, which upon examination would be found to be much jarred, and anything but round. The second objection was that it was too tedious and expensive to drill a small leading hole first, as a considerable amount of time would be occupied in changing the speed of the drilling machine from the slow speed, which had last been used for the larger drill, to a speed quick enough for drilling advantageously the smaller or leading hole. The change of speed

entailed the altering of the strap on the cones of the drilling machine, and in many cases the disengaging and again engaging of the double gearing of the machine. Both these objections were surmounted by using a twist-drill. If preferred, its point might be thinned down, in a grinding machine with small emery-wheel, to any degree of thinness which might be found best for penetrating without fracturing as in Fig. 29A, Plate 22; this was a simple mode of reducing the blunt end between the two grooves to any extent, thus meeting the requirements of Mr. Paget. By this system the point only needed to be thinned after about every sixth time the lips were re-ground; of course each re-grinding of the lips gradually caused the point to become thicker, until it was found advisable to reduce it again by grinding. With this system very heavy feeds might be employed, and a twist-drill 2 in. diameter had drilled one inch deep in wrought iron for every 62 revolutions; such a feed however he considered too heavy for every-day practice, and he preferred to use a feed, for drills over ½ inch diam., of 100 revs. per inch, as given in the paper, and not 200 revs. per inch, as suggested by one of the speakers.

While agreeing with Mr. Wicksteed that the less overhang a cutting tool or tool-holder could have the better, yet in actual workshop practice it was found impossible to avoid overhang altogether; and it would be found in going the round of any works, say for example the machine shop of a marine-engine builder, that probably forty-nine out of every fifty tools were obliged to overhang the slide-rests or the tool-boxes which carried them—in most cases to the extent of many inches of overhang—in order to reach the part which had to be operated upon. In numerous instances the cutting tool had to reach into deep corners and recesses, often as much as one or two feet deep: the tool or tool-holder having in many such instances to be made specially long. The few cases where overhang could be dispensed with were in turning a long hydraulic ram in a lathe, or a large straight propeller-shaft: the slide-rests of the lathe could then be brought almost touching the work, as in these examples there were no projecting arms, bosses, or anything of that sort to prevent it. Where however it was desirable to avoid overhang, the swivel tool-holder could be cramped diagonally on the

rest or tool-box; and even though a cutter of great length were then used, it might project as short a distance out of the holder as desired, so as to overhang not more than $\frac{1}{4}$ or $\frac{1}{2}$ inch, as illustrated in Fig. 50, Plate 24. Again, where in some special case exceedingly heavy cutting was required from the round tool-holders, then if it was considered advisable a narrow portion of the front part of the rest or tool-box might be recessed for the curved part of the tool-holder to lie solidly in, as shown in Figs. 51 and 52, Plate 24. By this means the round cutter might be brought up so close to the front of the slide-rest as almost to touch it; or else the old style of straight tool-holder could be used, drawn back on the top of the rest until there was no overhang. For such heavy cutting the tool-holder and cutter must also be sufficiently heavy and massive to convey the heat away. There was no particular limit to the size the tool-holders might be made; and they were all constructed of steel.

To test the stability and cutting powers of round tool-holders, he had made an experiment in a heavy 15-in. treble-geared lathe with 5-ft. face-plate, turning a hard Bessemer-steel shaft 8 in. diameter with a traverse of $\frac{3}{8}$ in. to each revolution. Care was taken to examine the amount of spring which really took place in the short overhanging portion of the tool-holder; a gauge was applied, resting on the solid saddle of the lathe, and high enough nearly to touch the cutter. Very little spring was discovered at this point, the slide-rest and tool-holder proving to be more stable than other parts of the lathe. The loose headstock, though very massive and secured to the bed by three large holding-down bolts, proved to be the weakest part of the lathe; its centre could be seen perceptibly to spring and rise when the cut was put on.

For roughing out very heavy iron and steel forgings, such as Mr. Hulse had alluded to, there was no doubt that the most speedy and least expensive system was to employ powerful machine-tools. From his own experience this applied also to smaller articles, such as pins and set-screws with collars and heads, studs, &c., which were roughed out and finished direct from the black bar-iron and then cut off: the whole being accomplished at one setting, and expensive smith's work being entirely avoided.

Mr. Anderson had referred to the finish of two joints, and asked which was the best. To all appearance the milling gave the finest finish; but by passing the fingers carefully over the milled part very slight undulations could be detected. This was simply because there was only one vertical milling machine at liberty to do that work at the time, and it was far too light and delicate for the purpose. Its circular table, which carried the joint, was only about 8 in. diameter; while the table of the slotting machine on which the corresponding joint was finished was about 24 in. diameter, and the machine proportionately heavy. The fact however must not be lost sight of that the milling was done in one third of the time occupied for the slotting. Milled work generally was better finished than shaped or slotted work: take for example the admirable specimens of workmanship sent from America, such as lathe and drill chucks, &c., which were finished direct from the milling machine with such wonderful accuracy that any hand-labour bestowed on them would only injure the fit; and this would apply to a great extent to the larger work. There was no reason why he should be biassed in favour of milling any more than of slotting or shaping: all he desired was to produce work in the best way and at the cheapest rate.

Mr. Longworth had asked why he did not adopt two cutting angles—one for cast metals, the other for wrought metals—as in the case of the round tool-holders. The objection to doing so was that there would have been much more complication, as double the number of tool-holders and cutters would have been required. The question had also been asked whether broad-cutting could be done with the tool-holder as correctly as with an ordinary tool. All he could say was he was constantly doing broad-cutting with tool-holders, and found that the machined work was better than he could produce by any other means in the planing machine. It was advisable in this case, when grinding the cutter, to give it as little clearance as possible. One of these cutters, which he had examined in the works, had not been re-ground for nine months, having simply been rubbed up on its cutting edge occasionally with an oilstone. The shavings taken by these cutters though broad were exceedingly thin; the cutters were probably not cutting one-twentieth of the time of

the roughing-out cutters, but in any case their endurance was extraordinary.

It had also been asked whether the rose-bit could be dispensed with. Though wonderfully good drilling could be done by good and correctly ground twist-drills, yet for exceedingly accurate holes, into which standard-size bolts or steady-pins had to drive tightly, or for holes in joints, links &c., in which pins had to work with perfect template fit, he himself used an adjustable rymer having three blades, which were capable of the finest adjustment in case of wear, in order to maintain the standard sizes.

Hard gun-metal he found might be quite as easily milled as cast iron; and the yellow brass and softer gun-metals could be even more easily operated upon, provided the milling cutters were coarse in pitch, so that there was ample room between the teeth to receive the cuttings. The milling cutters were particularly suited for finishing soft brass, and could be worked with double the feed used for iron: producing brass mouldings or other complicated forms with great accuracy, and with a very highly finished surface. Such mouldings had been milled at the rate of 2½ inches in length per minute.

As to cast steel for cutting, he simply used the best qualities which were found to be the most suitable for each purpose, using one make for twist-drills, another for milling cutters, and so on. He had made numerous experiments on different kinds of cast tool-steel; testing a tool made of any quality of steel which he had not previously used, against a tool made of steel which had hitherto given the best results. The trials were usually made in a planing machine having two tool-boxes on its cross-slide. One tool was fixed in the first box, and the other in the second one; and both were started to cut on the same casting (usually a lathe bed or planing-machine bed or table), cutting of course at the same speed, and with the same feed and depth of cut applied, so that the trial might be a perfectly fair one. But there was an extraordinary difference between steels. Some very hard steels, which would resist the file, seemed in cutting to perish away at the point. Steel which was hardened by simply heating and laying it down seemed, as far as he had tried it, to cut very satisfactorily, and to stand well; but there seemed to be one

peculiarity about it: the quality of the tool, as it was ground away, became softer than it was at first. That difficulty was obviated by taking it to the smith, and re-hardening it. As to cast-iron, he had had much the same experience as the President. One of the greatest difficulties with a chilled-iron tool was, that if the point of the tool did give way, it was exceedingly difficult to re-grind it; and although it was excessively hard, it did not seem to have great endurance. He had not yet however tried the effect of cutting chilled metal with a chilled cast-iron tool.

Mr. Fielding had asked the maximum speed of cutting. That was alluded to in the paper, p. 248. The maximum speed for cutting wrought iron with a single tool was about 40 ft. per min. In his small lathes, it was quite common to cut at the rate of 30 ft. per min. Of course the speed had to vary, as remarked in the paper, with the depth of cut and the quality of the metal. Mr. Reynolds, had he been present, could he believed have told them that he had taken off with one tool, running at a slow speed, half a ton of steel shavings per day.

He had been invited to go into a description of the machines used in connection with the tools; but to introduce any such matter would have made the paper far too long, though he might perhaps do so on a future occasion. Mr. Robinson had called his attention to the milling machines made long ago at the Atlas Works, which no doubt would still do good work if proper cutters were supplied to them. One practical difficulty, as Mr. Robinson had said, was in maintaining the cutters, before the emery-wheel and the mechanical system of grinding were adopted. The difficulty and expense of the old method were described in the paper, p. 244. Not only the making and finishing of the milling cutter, but also the maintaining of it in its proper state of efficiency, were exceedingly inexpensive. For instance a cutter would probably last a day without being re-ground; and to re-grind it occupied four minutes only. The cutter was simply placed in the grinding machine on a mandril, adjusting it by worm and worm-wheel till the teeth to be ground were parallel to the lower slides. The cutter was then passed rapidly, once forward and back, for the grinding of each tooth. The actual grinding of the whole cutter would not occupy more than 2½ to 3 minutes.

Replying to Mr. Robinson, the tools shown in Figs. 8 and 10, Plate 19, were the only two special forms out of the whole of the cutters shown, and only one of these required any forging. They were tools which were rarely used. All parts of the swivel tool-holders being made of tough forged steel, and the cutter being gripped with great rigidity by a powerful screw and nut, the whole was wonderfully free from jar.

Regarding the organisation of the best systems in workshops, his experience was that when this tool-holder system was once introduced the work went on with less supervision and anxiety to the overlookers, cost much less, and maintained a much higher standard of excellence.

Mr. Paget had mentioned the introduction of water through the tool to cool it. He had made a number of experiments for Col. Clay on that principle, and managed to cut at 40 ft. per min.:, but at the end of the day from one difficulty and another he found it had not finished more work than an ordinary tool, and consequently it was abandoned.

Mr. Hulse had alluded to the practice at Sir Joseph Whitworth's with regard to tool-holders, as to which it was not needful to go into details; and also to the tool-holders not being able to take heavy cuts. If for tools doing exceedingly heavy work, and taking such cuts as Mr. Hulse spoke of, any advantage was found in using the slide-rest, by all means let it be used. What he said of the tool-holder system was, that for 100 machines out of 101 it was applicable; and not only applicable, but it was cheaper and produced better work. Mr. Hulse also alluded to a single-pointed tool doing more accurate work than a number of cutting teeth; but surely it stood to reason that a single point could not last as long as a number of teeth, and maintain the same accuracy.

Mr. Kitson had alluded to the milling cutter with a spiral groove in it, cutting a portion of the teeth away. His own experience was that when you began to cut a portion of the teeth away, you were obliged to reduce the speed, or else sacrifice the quality of the work. Many trials had been made at the Gresley Works from time to time with ½-inch drills of ordinary form manufactured by himself, or by different engineers who had wished to see the effect of working a

common against a twist-drill. The result had been that if a feed were put on the common drill, approaching that used for the same size of twist-drill, the former was invariably fractured, while on the contrary the twist-drill escaped fracture in a marvellous manner. The feed used was often so heavy that the spindle of the drilling machine could be seen by the eye visibly descending. The drilling machines originally constructed by himself were provided with self-acting feeds, as coarse as could safely be applied for feeding forward the common drill. Since the twist-drill had been found to accomplish so much more work in a given time, he had increased all the feeds in his new drilling machines by about 90 per cent.

The President had described the work done by a flat drill, which drill was apparently machined all over and finished with great care, thus costing probably quite as much as a twist-drill could be purchased for. By that means no doubt all parts of the drill were made true and concentric with each other; and it would therefore be practicable to grind the cutting lips by machine so accurately, and to flute the cutting angles of the lips in such a manner, as to produce excellent cutting results for the short space of time the two flutes would keep in order. But he imagined that when the drill was worn, say $\frac{1}{8}$ inch shorter, the proper angles for cutting would be found no longer existing; and to restore them, $\frac{1}{4}$ inch of the length of the drill would have to be ground to waste, before two new flutes could be again ground into the lips, so as to restore the proper cutting angles. Or, worse still, in a work where the flutes could not be mechanically ground in, the drill would have to be heated to soften it. Immediately this was resorted to, the finished accuracy of the drill was more or less destroyed; whereas in a good twist-drill, used with care and re-ground mechanically, the cutting angles remained the same, however short the drill might be ground. This, coupled with the fact that the wear took place only at the end of the drill and that the drill was hardened its whole length, produced the result that no softening had ever to be resorted to; the grinding or shortening of the drill was excessively slow; and, there being no waste or expense in repairs, the cost of the twist-drill, spread over its life-time, was exceedingly small.

In Lancashire, on an approximate calculation based upon the employment of one hundred workmen, thirty of whom were turners and machine-men, the saving in wages where the tool-holder system was exclusively used, as compared with the old system of forged tools where each man re-ground them for himself, was £8 0*s.* 10*d.* per week. This did not include the advantage of producing a greatly increased quantity of work per day from each machine, nor any of the advantages derived from the twist-drill system.

ON IMPROVEMENTS IN THE MANUFACTURE OF COKE.

By Mr. JOHN JAMESON, of Newcastle-on-Tyne.

That products of great value may be obtained from the distillation of coal is no new discovery. The by-products resulting from the manufacture of coal gas have steadily risen in value for many years past, notwithstanding the fact that their production has enormously increased; and they are at the present moment of very great value.

More than once the suggestion has been made that all coal intended for fuel should be distilled before being burned, and that the volatile products so recovered might more than compensate for the cost of the distillation. If the products obtainable from coal could be presented to us in a separated form, probably the last idea which would occur to a rational mind would be to make fuel of the whole; and it seems safe therefore to predict that in the progress of science we are coming to a time when the use of raw coal for fuel will be looked upon as a barbarism of the past. In the crude products of coal, as most readily obtainable, there is a large quantity of water, which contains indeed ammonia, of great value if separated, but is of worse than no value as fuel; while in the tar and gas, separated by mere heating (and invariably separated, it is believed, whenever coal is heated), we have a fuel certainly, but one which not only is intrinsically of much higher value than a proportionate quantity of carbon, but which, when burned as produced in an ordinary furnace using raw coal, forms a positive nuisance and detriment.

The writer proposes on the present occasion to describe a process for the separation of the products of coal, which in his opinion combines the advantages of extreme simplicity and cheapness with high efficiency. It is applicable to any ordinary form of open coke oven, such as are in use in this country at the present time for the

conversion yearly of about twenty million tons of coal into metallurgic coke.

At the outset it may perhaps be well to explain what must be very elementary truth to many persons, namely that the products, which may be extracted from coal by various processes of distillation or otherwise, are not originally contained in the coal from which they are formed.

There is, for instance, no ammonia in coal, either in the form of free ammonia or salts of ammonia; but there are combinations of other bodies containing nitrogen and hydrogen, and in almost any process of distillation a certain part of the nascent nitrogen, uniting in conditions of extreme obscurity with a certain portion of nascent hydrogen, produces the compound called ammonia; which is thenceforth more or less persistent, if protected from adverse influences, but is decomposed most readily if exposed to conditions in which its contained hydrogen may leave the nitrogen in favour, for instance, of a union with oxygen. The remark applying to ammonia—namely its non-existence originally in the coal and its formation during the process of distillation—applies equally to every known volatilised product. The elements from which the products are formed exist in the coal, but the products themselves do not.

It is not as a matter of mere curiosity that the writer desires to give prominence to the apparent anomaly that we get out of the coal we are dealing with something which was not in it: but as a point of extreme importance, and one necessary to be kept in view if we would arrive at a right understanding of the merits or disadvantages of any means which may be proposed for the transmutation of certain matters in the coal into more valuable products.

In a process of what is called quick distillation with extreme heat, it is said that the products formed differ very materially from those formed by what is called slow distillation at a less degree of heat. In the former there is a larger production of permanently elastic gas, rich in carbon, and possessing therefore, when burned by itself, a high illuminating power; and there is necessarily a smaller proportion of condensable vapour: while in the latter case there is produced a

larger proportion of hydro-carbon vapour, and a gas which, when thus robbed of its condensable products, possesses in itself little illuminating power.

The perfection of this slow distillation may be observed in the gas escaping from a marsh, or in the fire-damp of a coal mine, where a gas is produced having a small proportion of contained carbon and possessing little illuminating power; while the perfection of quick distillation on a practical scale is that of a gas works, giving a gas with a much larger proportion of contained carbon, and a much higher illuminating power. The aim of the gas company is to supply in the gas as much of the hydro-carbons, in the form of a permanently elastic gas, as it is possible to produce; and to have therefore as small a proportion of condensable hydro-carbons as may be. But if on the other hand condensable hydro-carbons be desired, the gas should be as nearly of the nature of marsh gas as may be, and non-luminous; in order that the volatilised carbon may enter into other combinations.

In illustration of this point may be taken a well-known process of using paraffin or petroleum, or any analogous substance, by injection into a red-hot closed retort. In this process, by the action of intense heat, one hydro-carbon is decomposed, and another hydro-carbon is produced, the former being solid or fluid, and the latter being in part permanently gaseous, in part perhaps more or less deposited in the retort as coke. A hydro-carbon, which would in this way be decomposed, might with less heat be merely distilled, and condensed almost unchanged in constitution.

The consideration of this action suggests the thought, that perhaps in any process of the distillation of coal, whether called quick or slow, if we could follow the action occurring, it might be found that all the hydro-carbons first disengaged are wholly condensable, and exactly of the same character; but when the disengagement occurs in an intensely heated retort, the gases and vapours, being immediately subjected to a more intense heat on escaping from the particle of coal from which they were disengaged, suffer a second decomposition; and perhaps again and again the proportions of combined carbon and hydrogen may be changed in successive decompositions, so as to

produce what is in fact produced in the gas works: namely many groups of hydro-carbons of different composition and construction, together with carbon not chemically combined but mechanically mixed in the tar. This carbon is no longer capable of being volatilised by heat, as it once had been when chemically combined, but by the process of destructive distillation passes successively into pitch and then into pitch coke. If the carbon of this pitch coke could be recovered, chemically combined with the hydrogen of the gas, we should either have an immensely increased value in the gas, or else an increase in the condensable hydro-carbons, perhaps to a corresponding value.

In estimating therefore the value of the products contained in coal, or rather producible from coal, it is not right to assume that the condensable matters are merely those obtained in gas works. They may be expected to increase in quantity, at least in proportion as the gas is deteriorated in illuminating power, and in proportion as the vapours disengaged are protected from the second and succeeding influences of heat. Taking however the products produced in gas works, as exhibiting well-known figures which may form an agreed basis for argument, the value of the products lost in the ordinary process of burning raw coal is something quite enormous.

In the first business the writer engaged in, he had to watch carefully, and frequently to complain that amongst the ammoniacal water of some of the London gas works, purchased at 1*s.* 3*d.* per 108 gallons, there was an unreasonable quantity of tar; the whole being charged as gas liquor. Objection was thus made to a material, then supplied at fifteenpence, which to-day is worth twenty-seven shillings. The firm had no use for it, and were in turn complained about for allowing any part of it to get into the Thames, or into the ditches of the Isle of Dogs. That difference in value represents the advance during a little over thirty years in dealing with the products of coal; and considering how, from those products, the richest and most gorgeous colours, the most subtle essences, illuminants, lubricants, disinfectants, and fertilisers, to say nothing of our most valuable servant gas, are all at present extracted, our progress in the past forms no gauge as to the possibilities of the future.

In regard to the loss as estimated by gas-work figures, it may be stated roughly per ton of coal at 10 gallons tar, ammonia equivalent to 20 lbs. of sulphate, and gas to the extent of about 10,000 cubic feet. The value of the tar may be stated roughly at about £3 per ton, while the value actually realised as fuel is probably less than the value of an equal weight of coal. The ammonia is of immense value in itself, and its value as fuel is even less than that of the tar. There is a large quantity of water contained in coal and liberated in closed retorts, and a still larger quantity produced in the consumption of coal, the value of which, as fuel, presents a serious item on the negative side. In regard to gas, although it cannot be denied that it possesses a high value as a fuel if properly burned by itself, the two facts—firstly that its formation in furnaces or fires is intermittent and variable in a very great degree, according to the condition of the fire, and secondly that it and the tar require a very large proportion of air to burn them, compared with the proportion required by the carbon of the coal—occasion the result that, if we admit air adequate to consume the maximum quantity of gas, we necessarily admit air in excess of our requirements when the evolution of gas is less active. Even with an arrangement for regulating this admission of air, and with skilful firing, the actual weight of gas evolved in a furnace is, as mere fuel, of less value than an equal weight of carbon. No doubt when burned separately its value is great, and is enhanced, notwithstanding deficient intensity of heat, by the fact that 60,840 units of heat are generated by the combustion of a pound of hydrogen, as compared with 14,220 units produced by the combustion of a pound of carbon; but burned in the manner here considered it is necessarily so extravagantly and wastefully consumed as to fall much short of the value of an equal weight of carbon.

Conclusive demonstration of the truth of this opinion is afforded in a report recently presented to the Coal Trade of Northumberland and Durham by Messrs. H. Ayton and T. W. Bunning, describing experiments at the International Exhibition for the Abatement of Smoke, in December 1881 and January 1882. In one comparative trial, page 14, Nixon's Navigation coal was used against best round North-country coal. The firing was certified as experienced and

satisfactory with both descriptions of coal (as it must have been to get so good results); the conditions were as nearly as possible alike, Martin's fire-doors being used; and the effect produced was an evaporation of 13·25 lbs. of water at 212° per lb. of Nixon's Navigation coal against 12·22 lbs. per lb. of North-country best round coal. The quantity of clinker produced was nearly alike with both coals; but the quantity of ash was double in the Welsh coal, part of which ash was no doubt capable of yielding further heat, and in proper conditions would thus be capable of still further magnifying the difference due to the consumption of gas as against the consumption of carbon.

There seems no possible explanation of the result given, excepting that the gaseous products of relatively bituminous coal (such as that of the North) do not in even the best actual practice come up in value as a fuel to the relatively carbonaceous coal (such as that of South Wales); and *à fortiori* in ordinary practice they must fall far short of it.

There can be no question as to the high value of gas as fuel, unless for the most intense heat; and even if a very intense heat be required, still by the previous heating of the gas, and of the air required to burn it, it may be used with great convenience and advantage. But in the ordinary furnace, where the gas is evolved intermittently in very variable quantities from the coal consumed, its value is less than the value of an equal weight of carbon; while from its imperfect consumption and its production of smoke, and from the alternative of either most close attention or most wasteful admission of excessive quantities of air, its inconvenience and costliness are very great indeed.

With the ordinary domestic fire, it is to the presence of the gas imperfectly burned that we are indebted for the canopy of smoke disfiguring our towns, for the aggravation of the London fogs, and for discomfort, annoyance, and injury to health, which it is possible to realise but not to express.

If in a well-constructed furnace the gas and condensable products of coal are of less value than an equal weight of carbon, much more is this the case with the open domestic fire, from which probably a

large proportion of the gas escapes entirely unburned, and a large proportion only partially burned. Should we however assume that in our domestic fires all the gas is completely burned as fuel, the questions arise, and may be said to answer themselves:—(1) whether this is the use to which the gas should be applied; (2) even if this were so, whether the open fire, with its most wasteful consumption, is the right way to apply it; (3) whether by previous separation we might not be able to save what should clearly not be burned at all, namely the condensable hydro-carbon products and ammonia; (4) if for brightness and cheerfulness we are to have flame in our fire-place, could we not arrange to have a regulated supply of previously-separated gas, so as to ensure its perfect combustion; and to use the separated fixed carbon in the coal in the form of coke nuts? In the circumstances last supposed, gas could be used for lighting the fire, regulation of temperature would be brought within the most perfect control, and a steady fire might be maintained at the lowest cost.

The methods which are in existence for such distillation of coal are as follows:—(1) distillation of coal in retorts, which is objectionable on the ground of the costliness of the process and the inferior quality of the coke produced; (2) distillation in close ovens, which, while it is a more valuable and successful process, is objectionable on account of the costliness of the ovens, and the difficulty and loss arising in the rapid transmission of heat through a bad conductor, necessarily of considerable thickness; (3) distillation by a blast of heated air and gas, delivered into a nearly close oven under some slight pressure, which process is a most important advance in regard to the transmission of heat, but is objectionable on economical and other grounds; (4) the writer's own process, which is at least in the last degree simple. The divergence of this new process from the process of manufacture of coke as carried on at present in an ordinary coke oven is so slight, that even the man in charge often could not tell whether the ordinary or the new process was in use.

It is hardly possible to imagine a more close analogy to this process than is furnished in the smoking of an ordinary tobacco-pipe. There is one important difference, it is true, but the principle is illustrated in other respects completely. The difference is that in the tobacco-pipe the whole of the fuel is *consumed*; in the coke-oven, by the combustion of the surface coke, and by confining the heat under a brick arch whence it is again radiated to the charge, the greater part of the contents of the oven are *carbonised* only, not consumed.

During this carbonisation of the charge of coal (igniting from the top as it does and gradually extending its heat downwards) the effect is produced of a gradually-increasing heat passing slowly through all degrees of temperature up to that of intense incandescence. In ordinary circumstances, with the present process of coking coal, the gases and vapours evolved find their way to the surface of the charge in the oven and there suffer decomposition; in the writer's process a pipe is introduced in the bottom of the oven, and while the operation of coking is going on in all respects in the ordinary way, the application of gentle suction to the pipe in the oven floor causes the evolved gases and vapours to be withdrawn as they form. By regulating the suction we can take any quantity away that is desired.

And just as it happens in the tobacco-pipe that a deposit of oil, in fact a tarry oil, is formed in the cool stem, so in the suction-pipes of the ovens we get tarry oils and ammonia in very large quantities. It is of course possible to apply such a force of suction, and to continue it so long, that a large portion of the contents of the oven might be burned away; and this must be avoided. But it fortunately happens that in the process of coking bituminous coal (the only coal fit for coking, or containing valuable products), there is a seal formed between the incandescent coke and the raw coal, which seal is due to the exudation of pitchy hydro-carbons, and the softening of the coal itself. This seal is a very effectual bar to the passage of air, so that, even if the suction should vary within moderate limits, there is yet no through draught.

The formation of this seal is incidental to the manufacture of coke. The separated particles of coal run together. Above the seal is coke actually formed, below it coal entirely raw; but within it is a successive series of varieties of product due to the difference of heat, and to the soaking down of the more fluid products of the coal; and there is thus a process of distillation going on, and an evolution of gas, not in one part, but in all parts of this band of consolidating coal. The tenacity of the mass is greatest on the upper side, and diminishes gradually to entire softness below.

The natural effect of suction below this seal is to take away the evolved gases, and the products of distillation; and as the passage of the gases is downwards through the cool raw coal, this most effectually prevents their undergoing any second decomposition by extra heat. In fact the gases are cooled, and at the same time impart a slight heat to the lower strata of coal, and so further the process.

The action of the process may be made clear by means of a diagram, Fig. 1, Plate 25, giving an imaginary section of a coke oven with the writer's process of coking in operation. The depth of shading in the charge of coal indicates the progress of the heat downwards, which, it will be observed, is not represented as a regular and uniform progress. No doubt, if it was a question of merely bringing to incandescence a mass of dry sand, or some similar substance unchanged by heat, there would be a uniform, or nearly uniform, series of curves or straight lines of decreasing temperature, dependent upon the degree of heat applied and upon the conducting power of the body through which it had to be transmitted. But in coking coal we are dealing with a material in which great chemical and other changes are going on. We have an immense absorption of heat, at a certain part of the charge, due to the evolution of gas; and we have also an absorption of heat due to the evaporation of water and to the volatilisation of condensable hydrocarbons, a part of which heat is again given out in the condensation of these vapours in the cooler lower strata of the charge.

The writer cannot pretend to calculate these effects with any degree of accuracy, as they vary at every moment. But by means of perhaps an exaggerated representation of an oven under similar

conditions, in which the volatile contents are lost in the usual way, Fig. 3, Plate 27, he will endeavour to explain the appearances shown. In the ordinary oven, the volatilised gas, vapour of water, and vapour of hydro-carbons, liberated below the incandescent portion of the charge at varying degrees of temperature, pass in an opposite direction to the heat, and, if one may be allowed the expression, wash back the heat to an extent represented by their quantity, their capacity for heat, and the difference of temperature between that at which they are formed and that at which they escape from the charge. This is represented by the gradations of lighter shading, rising towards the surface in Fig. 3. In the modified oven under consideration, Fig. 1, Plate 25, the gases and vapours convey forwards in the direction in which it is wanted the heat they contain; and beyond doubt, in the early stages of the process, the condensation of the vapours in the cold coal and the liberation of their latent heat cause a more rapid and effectual heating and give an appreciable benefit of some importance. This is represented by the gradations of lighter shading tapering downwards in Fig. 1. That there is an absorption of heat due to the causes above mentioned, and also a giving out of heat again, is demonstrated by the fact that in ordinary circumstances, when taking away about 200 cub. ft. of gas per hour per ton of coal in the oven, and when continuing this rate of withdrawal for about 60 hours, the temperature of the pipe on emerging from the ground does not average above 180°.

In the experiments hitherto carried on, a Root's blower has been used for exhaustion; but with a well-governed engine, and for a large range of ovens, probably a fan might be found more convenient. The amount of suction is very small, only from ½ in. to 4 in. of water.

A steam engine has hitherto been used for exhaustion, and the gas chiefly as fuel for the boiler; but there can be no doubt that a well-constructed gas engine would be infinitely preferable, because an immense quantity of gas would be saved and made available for other purposes.

Fig. 1, Plate 25, represents a section of one of a range of ovens, with the suction pipe leading to a series of five main gas-pipes, and

having provision of valves for passing the oven-gas into each in turn, so as to secure some difference in qualities in the gas, and also a species of fractional separation of products, which the writer believes to be of great importance. From this range of ovens, the discharge of gas is passed after twelve hours, or at any other convenient interval, into the second pipe for separate condensation, while another range of freshly charged ovens discharge into the first pipe; and so on throughout the series. As we may continue to apply suction through the last main pipe, during the quenching of the last range of ovens, we thus obtain, together with a clearance of the pipes from adherent oil or coal dust, a considerable quantity of carbonic oxide and hydrogen gas, and an important quantity of ammonia, which might otherwise be lost in the quenching water. This takes place through a separate main, without dilution of the products previously recovered. Each main discharges its contents into a separate condenser; but, unless the gases are to be separately used, the mains may of course be exhausted by one fan common to all.

Fig. 2, Plate 26, is a plan of the oven bottom, showing a series of channels leading to a central orifice, the channels being covered with perforated quarls.

The only point which is of special importance in the working of the process is to keep the oven-bottom tight against access of external air. To prevent access of air through the ground, there should be a layer of some impervious material, such as pitch or cement, at such a distance below the floor of the actual oven as not to be destroyed by the heat; and as much as possible the walls of the oven, if it be a new one, should be similarly protected. Although good results may be got with very imperfect arrangements in this respect, yet, if the heat be adequate, there must be for every access of air a certain amount of loss by decomposition of products; or at all events an increased proportion of nitrogen in the gas, which injures its value. If access of air could be entirely prevented, the gas would be of the full value of retort gas, less the effect of the thinness due to the increased production of condensable hydro-carbons, but with considerable heating power, due to its hydrogen. If however there be considerable access of air, the gas may come down to be little better

in value than producer gas; and the hydrogen may be consumed not only with no beneficial effect, but with absolute loss, and with an enhancement of the cost and difficulty of condensation.

It is hardly necessary to say that from different varieties of coal very great variety of products, both in quantity and quality, may be obtained.

In some cases the products obtained in the condenser, exclusive of the value of the gas, have been of more value than the coal operated upon, *plus* the cost of coking; so that in fact the coke was got for nothing. In other cases, with a more valuable coal, the products, exclusive of the gas, form a smaller but always an important item. In many carefully conducted experiments, absolutely no difference has been found, in yield or quality of coke produced, between contiguous ovens worked in all other respects alike, saving that in one the withdrawal of the products was effected on this process, and in the other they were burned in the ordinary way. It is difficult to give an average yield of products with various coals; but Mr. W. W. Pattinson, of Felling, who has experimented on a very large number of five-ton samples, believes we may confidently expect on an average a yield of 8 gallons of oil, ammonia equivalent to 10 lbs. of sulphate, and gas to the extent of 10,000 cubic feet per ton of coal. He is satisfied that in all the experiments hitherto conducted there has been a very considerable loss of products due to imperfect condensation and undue exposure.

The oil is sometimes rich in paraffin of high melting point; and it contains many other valuable ingredients besides.

The conclusion to which it is the object of the paper to point is simply this, that it is at least desirable by some means to separate from coal the products contained in it which are of little or no value as fuel, or are even worse than useless, but are of great value for other purposes.

We are dealing with a production in this country of one hundred and fifty million tons yearly. Part of this coal is already coked in gas works, part is unfit for coking, and part does not contain the products that are of value; but on the other hand, the extraction of

products would probably bring into use a quantity of duff and small coal now left in the pits or otherwise wasted, which would more than compensate for this difference; besides which, shale and many matters now wasted can be dealt with and will afford products of great value. Hence no correction for other less productive coals appears to be necessary. Taking the above quantity, and using gas-works figures, as at p. 279—estimating the gas at only 6*d.* per 1000 cubic feet, the tar at 3*d.* per gallon, and the ammonia at 1½*d.* per lb. of sulphate producible from it,—the total value of these products is 10*s.* per ton of coal, or £75,000,000 a year. Cut and carve this gross total as we may, a vast sum must remain, the recovery of which, if it be recoverable, must be regarded as one of the most important scientific questions of the day.

The attainment of this object alone is of immense importance; but the writer desires also to point out that, when accomplished, its attainment will be accompanied by very great convenience, by very important sanitary improvement, by entire suppression of the smoke nuisance, and by economy in the actual amount of fuel used for whatever purpose, independently of its cost, or of profits otherwise derived from it and already summarised.

He is not specially advocating a particular process for the accomplishment of these objects. There are various other processes in use, and he most fully admits that each may be the best process in regard to local circumstances, to some precise and definite object to be obtained, to the quality of the coal dealt with, or to other considerations.

There is room for all, and no special pleading can affect the law of survival of the fittest, inflexible in manufacturing processes; but he believes that by a great deal of most able assistance he has got into practical shape an extremely simple and very efficient process, and in particular a process applicable to an enormous amount of existing plant.

Abstract of Discussion on Improvements in Coke Manufacture.

Mr. Charles Cochrane said if the somewhat astonishing observation at the end of the paper was true, and if 75 millions a year could be saved, he thought it would be a disgrace if they did not at once set about saving it. But in considering the subject, it would be well to refer to the ordinary conditions of work in a bee-hive oven. It might be supposed that little air was admitted to that oven, because it was not intentionally admitted; but, as a matter of fact, the process in that oven did involve the admission of a great deal of air, whether it was acknowledged or not. That air was drawn in through the cracks and fissures of the brickwork, and was responsible for a waste of at least 7 per cent. of the coke that should be realisable out of the fuel—possibly 10 or 12 per cent. It was of the utmost importance therefore to get the air under control; and the more they brought the air admitted into contact with the gases evolved, without its coming into contact with the coke, the more economical would the oven be in its yield. Heat would be developed by combustion of the gases themselves, and would heat the arch of the oven, which, by re-action on the surface of the coking mass, tended to favour the yield. They might carry that a step farther by warming the air first; this had been done in a large establishment in the North of England, and the direct result was an economy of at least 7 per cent.; but his impression was that it would be made to reach at least 8 or 10 per cent. The air was warmed by introducing it over the top of the oven dome, and after allowing it to course over the dome it was admitted into the body of the gases under the dome so as to ensure their combustion without injury to the coke below. The heat so produced was so intense that the ovens were able in 72 hours to do work previously done in 96 hours: at the same time securing that magnificent large coke which furnace-men were so fond of, and also bringing about an actual increase of 33 per cent. in the out-put of the ovens. That was being regularly done, not only at the New Brancepeth Colliery near Durham, but also at Woodside near Dudley, where the results had been equally good.

In reference to the quality of the coke, he believed it was a fact that the hardness increased, the higher the temperature to which the coke was subjected in the process of manufacture. That was a general rule, although there might be exceptions. At the Bessèges establishment of the Terre Noire Company, in the South of France, they had made experiments on the crushing strength of the coke produced at increasing degrees of temperature; and whereas with the ordinary beehive oven they obtained a crushing strength of only 618 lbs. per sq. in., they now were able, by subjecting the coke to higher temperatures than could there be realised (by means of external flues, &c., and by reducing the thickness of the coke operated upon), to raise the crushing strength to 934 lbs., and ultimately to 1298 lbs. per sq. in. That seemed to point to the absolute necessity of securing a high temperature by some means or other, either by getting the gas properly burned, or else by sacrificing a certain amount of coke. In blast-furnace practice it was of the utmost importance that the coke should be hard. Mr. I. Lowthian Bell had pointed out in a most practical way the mischief that was done in a blast furnace by the use of soft coke, bringing about that dangerous chemical re-action between carbonic acid and carbon, to which he had so often drawn attention. By reason of its not presenting a compact and resisting surface, soft coke was more readily operated upon by the carbonic acid, to the absolute absorption of part of its carbon, which was carried away at the tunnel head, and never reached the tuyeres at all.

He observed in the paper that the author claimed no saving in the yield of coke; therefore the conclusion was inevitable, that if he did get his coke equally good, it was at the expense of some of it being burned by the admission of air. Not only had he to deal with the admission of air to the escaping gases below the coke, but also with another difficulty to which the paper had not called attention—namely the drawing in of air upon the surface of the coke itself, thereby burning coke on the surface, as in the ordinary beehive oven.

As to the economy of the process, he did not think the author was out of the way in valuing the gas at 6*d*. per thousand cub. ft. where it

was saleable; it was absolutely necessary however that there should be a demand for the gas before it possessed any value at all. Now a coke-oven plant was usually situated in the neighbourhood of a colliery: so that you must take blast furnaces, mills, and forges to the colliery, in order to avail yourself of the gas. For if you took the ovens to the blast furnaces &c., you would have extra freight on the coals, which would far outweigh the 6*d.* per thousand in the value of the gas. On the other hand, if you took the works to the colliery you might probably place yourself at a disadvantage in the cost of materials &c.; so that he considered that to value the gas at 6*d.* per thousand cub. ft. was an assumption wholly unwarranted. The only real value he could see attaching to these gases, beyond what was needed to raise steam at the colliery, was in the direction of the Simon-Carvès process, where the products were first taken out, and the gases were then used in order to warm the oven all round. Practically the effect was to place the oven in the position of a gas retort, to which no air could gain access. He did not want to go into the question of the comparative merits of the two processes, but rather to consider the use to which these gases could be applied.

Another point was the difficulty of maintaining the process in operation. It was said in the paper that there was a gluey or viscous substance formed below the glowing mass of coke, and he could not himself help thinking that the holes in the quarls, Fig. 2, Plate 26, would by-and-by be choked up; thus there would be considerable trouble in keeping the floor free for the equal distribution of the gas all over its area, and for the prevention of localised coking in the oven. In addition, he could not see how the plan was applicable to existing plant, until it were literally pulled to pieces in order to provide the means of preventing the access of air to the passages under the floor of the oven. This, the author said, was imperatively necessary; and this he himself also believed to be imperatively necessary in order to prevent the total failure of the process. If any air could creep in below, it immediately destroyed the value of the products.

As to the actual value of these products he was sorry to say that he had not, in his own case, realised anything like the value which

the author hoped for. He only got per ton of coal 3 gallons of oil, and 5 lbs. of sulphate of ammonia; and taking the former at 3*d.* per gallon, and the latter at 2*d.* per lb., it only came to 1*s.* 7*d.* as the total result; and he did not know at what cost that was to be obtained. The yield of coke at the time was 58½ per cent. It was true this result was only on one trial lot; but it was Mr. Pattinson's report of what he had been able to do, by the employment of Mr. Jameson's process, with coals raised at the New Brancepeth Colliery. He hoped the author would state the actual cost of the appliances he proposed to introduce, the working cost of the process, and the actual market value of the products, excluding the gas, because he did not think they could take credit for any of the gas which they could not consume themselves.

Mr. BERNHARD SAMUELSON, M.P., F.R.S., thought it was impossible to say that any paper which drew attention to the value of the products which were now wasted in the manufacture of coke, and generally in the consumption of coal, was without considerable value; but at the same time he could not help thinking that very much greater value would have been attached to it, if the author had done what, for instance, Mr. Ford Smith had done—namely present them with specimens of the coke produced by the apparatus to which their attention had been called. They would then have had the means of testing by actual specimens the value of the coke produced by the process that had been explained.

The paper had spoken, p. 281, of another process—that in which distillation took place in close ovens; and had spoken of it as being objectionable on account of the costliness of the ovens and the difficulty and loss arising in the transmission of heat. But it was important that it should be known that by means of the process there indicated—which was in fact the Carvès process*—coke of

* According to this system, shown in longitudinal and transverse section in Figs. 6 and 7, Plate 28, the coal is rapidly carbonised by subjecting a comparatively thin layer of it to a high temperature in a closed and retort-like vessel. Whilst in the beehive oven the volatile products and a large proportion of the coal are wasted, or burned inside in the presence of atmospheric

extreme density was obtained, and that in the production of that coke there was an enormous saving in yield; for whereas in the ordinary beehive oven (and Mr. Jameson claimed no economy over

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air, in these coke ovens they are burned around the outside, and only after they have been deprived of the tar and ammoniacal liquor. Each oven is in the form of a long, high, narrow chamber of brickwork; and a number of these are built side by side, with partition walls between them sufficiently thick to contain horizontal flues, AA, Fig. 7, Plate 28. Flues BB are also formed under the floor of each oven, and at one end of these is a small fire-place C, consisting of a small fire-grate and ash-pit with suitable door. The fire-door has fitted above it a nozzle, through which gas produced during the process of coking, and after it has been deprived of the by-products, is admitted to form a flame over the fuel burning on the grate. The grates are charged only twice in every twenty-four hours, their function being really only that of keeping the gas ignited. According to a recent improvement, hot air is introduced into the flues together with the gas; and as the air is heated by means of the waste heat in the flues which are conducting the products of combustion to the chimney, a considerable increase of temperature is imparted to the ovens at no expense of fuel. From the fire-place the gas, mixed with the heated air, passes forwards through one of the horizontal flues B underneath the bottom of the oven to the far end of the oven, and thence back again through the other flue B; it then ascends by a vertical flue in the partition wall to the uppermost of the horizontal flues AA formed therein, and descends in a zig-zag direction along these flues, finally passing into flues F outside the oven, and so to the chimney. It is these latter flues F which are surrounded by the air-flues, and so serve to recover the heat which would otherwise be lost.

It must be mentioned that no air whatever is allowed to enter the coke ovens: these in reality are hermetically sealed, with the exception of the opening for the volatile products, which are drawn off by an exhauster.

The retorts are fed with coal through holes in the roof, over which trucks are run on rails, as in the case of the ordinary beehive oven. The feed-holes are provided with covers kept tightly luted during coking. The two doors at the ends of the oven or coking chamber must also be kept well luted. Through the middle of the roof rises a gas-pipe provided with a hydraulic valve G, Fig. 6, which closes the passage by a lip projecting down from it into an annular cavity surrounding its seating. In this cavity it is immersed in a quantity of tar and ammoniacal liquor, lodged there during previous distillations. The volatile products of the coal distillation rise through the gas-pipe, and are led through a range of pipes kept cool by external wetting, so that the tar and ammoniacal liquor become condensed and separated from the combustible gas.

the beehive oven) a given quality of coal would produce from 58 to 60 per cent. of coke, by the process which Mr. Jameson condemned as being costly as much as 75 per cent. of very superior coke was obtained. But to show how much depended upon the quality of coke, he might state that, although the process had now been at work for something like sixteen years in France, the French iron-masters had hitherto hesitated to adopt it (with the exception of the Terre Noire Co.) because they had not been satisfied that the coke would produce as good results as the coke which was produced by the beehive oven. That difficulty, he believed, had been overcome, as the process was now carried on at the colliery of Messrs. Pease. The coke, which he had himself seen, was certainly such as could not be excelled in the beehive oven. If that were the case, he thought one of the merits which Mr. Jameson claimed for his process—namely that it enabled the old beehive oven to live—was one which should really condemn it; because if it were possible by a more improved oven, even apart from the saving of the by-products, to produce coke of equal quality and with a yield 25 per cent. greater (namely an increase from 60 to 75 per cent.), the sooner they condemned the old beehive oven the better.

He had said that any paper which called attention to the desirableness of saving the by-products in coke was of importance; but he quite agreed with Mr. Cochrane that there could be no advantage in exaggerating that saving; and to say that the gas and products could be recovered from 150,000,000 tons, under circumstances where they could be economically applied, could hardly be intended as a serious statement. All must be well aware that there were numerous cases in which it would be impossible to realise those savings, and at the same time to do the work at the place where it could best and most economically be carried on. And there was another question to be taken into consideration; namely, where were they to find an outlet for the quantities of waste products—tar, ammonia, etc. It had been found already, since the gas-works had begun to recover those products, that their value had diminished enormously. He believed within the last six or eight months the price of anthracine had fallen from 2*s.* 6*d.* to 1*s.* per lb.; and if those

enormous quantities should be produced which were hinted at by Mr. Jameson, he really did not know what use would be made of them. It was quite clear that the quantity required for producing colours for calico printers must be a limited one. And with respect to ammonia, although it was probable that the demand might be capable of very great increase at a lower price, it was quite clear that at the present price the demand was very limited. He believed that the sulphate of ammonia which was now produced in this country was almost entirely taken for export, especially for growing sugar beet: the use by English farmers was, he believed, comparatively small. No doubt, if the price were very considerably diminished, the demand would increase very much. But he did not think it was desirable that the sanction of the Institution should be given to a statement so evidently exaggerated as that which had been put forward by Mr. Jameson.

Mr. H. Bauerman said that the paper was very suggestive on many points; but upon the main point he agreed with the previous speaker that they had not had sufficient facts before them as to the working of the particular oven to which reference had been made. That the oven was likely to be a good one for the purpose of obtaining condensable products he could very well understand; because it was really, as applied to coals, the same as the Finland and Lapland tar-burner's kiln. In those countries, when the object was to make tar, they got root-wood, and dug a hole in the face of a bank, and then put up a polygonal funnel of boards in front. In that hole the wood was charged, the hole was closed up at the top, and the wood was fired much as in a kiln: the tar condensed, and passed out at the bottom. The charcoal that was made in that way was exceedingly good, but that was in part due to the fact that the material was exceedingly good. But, as Mr. Cochrane had pointed out, for metallurgical coke, and more especially for the purposes of the blast furnace, where dense coke was required, he thought the construction disadvantageous; because it lost the heat derived from the gases, which at present were burned in the top of the oven and tended to heat it. These were now taken

away, and they did not appear to be returned to the oven for the purpose of heating it. So that the process would rather seem to be one in which in the interest of the condensable products the coke was likely to be deteriorated. The perforated quarls again, Fig. 2, Plate 26, would seem to be rather liable to choke up; though modifications might be used in the construction to obviate that evil. But in all cases where you were burning fuel and generating combustible gases it was better to put them to their immediate use on the spot. There was nothing better than the use of a narrow prismatic oven, such as the Coppée oven, with a system of heating flues around it, where the heat could be got up rapidly and the coal uniformly heated. With regard to the author's estimate of the large sum theoretically possible to be realised from those combustible products, the results, where they had any before them, did not by any means bear it out. With the Otto oven, which was one of the most perfect of that class (the gas being returned to the oven after passing through the condenser), the saving in tar and ammonia, with Westphalian coal, was stated at 2*s.* 9*d.* per ton; and that was to a certain extent subject to reduction. Therefore it seemed only possible to realise a comparatively small proportion of the value suggested, apart from the value of the gases; and he did not think even that would be worth doing, in any case where the coke was at all likely to be deteriorated. The object of a coke oven was to make good coke in the first instance: of course if you could condense the products so much the better, but the quality of the coke should be the first thing considered.

Mr. B. G. Nichol said that some months ago Mr. Jameson's method of recovering the volatile products had been explained to him; and the design seemed so simple and promising that he was induced to make some enquiries into the operation of ovens on that principle. He endeavoured especially to ascertain whether there was any difference in the quality of the coke produced, or any increase or reduction in the quantity; and what were the proportions of oil and ammonia contained in the products. By the favour of Mr. Ernest Bell, he had had the pleasure of seeing in operation at Page Bank

nine ovens fitted on Mr. Jameson's principle, and Mr. Bell stated most emphatically that their first consideration was coke; and that they would sacrifice neither quality nor quantity, nor would they increase the time of production, for the sake of the by-products. If they got the coke exactly the same as before, and got by-products more than sufficient to repay the alterations of the ovens, well and good. Mr. Bell stated to him that the cost of altering an ordinary oven to Mr. Jameson's principle ranged from £8 to £10. He also showed him large quantities of coke produced by the ordinary ovens, and several wagon-loads of coke produced in ovens fitted on Mr. Jameson's plan; and there was no apparent difference in samples picked at random from each: they seemed to be of the same hardness and consistency. Mr. Bell stated that they had been unable to discover, mechanically or chemically, the slightest difference between the specimens made in the one oven and in the other; and that the yield was also precisely the same. The usual time for burning a charge, with each system, was seventy-two hours, and they did two charges per week. The results per ton of the coals they were burning were 4 gallons of oil, and 10 gallons of ammoniacal liquor, equivalent to 2 lbs. of sulphate of ammonia. The process of recovery being entirely automatic, there was no more labour or attention required than with ordinary ovens; and after paying the cost of alteration, each gallon of oil obtained was so much clear gain.

By the kindness of Messrs. Pattinson he had had the pleasure of seeing at Felling a number of ovens fitted on Mr. Jameson's plan, which had given much higher results than were obtained at Page Bank. When he got there a charge had just been drawn, and the quantity of oil had been measured, and the amount of ammoniacal liquor had also been obtained and the strength of it ascertained. From five tons of coal the result was 74 gall. of oil, or 14·8 gall. of oil per ton, and ammoniacal liquor equivalent to 16·4 lbs. of sulphate per ton. A large part of the difference in the results secured at Page Bank and at Felling was no doubt due to differences in the quality of coal used; but he thought that a large part was also due to the sizes of pipes employed and to the proportion of condensing

surface. At Page Bank the oil and liquor were drawn from the recess below the oven, by a Root blower, through two pipes 3 in. diameter to a trough about 12 ft. distant, where they were united, and the oil allowed to flow into another trough; the gases then passed up and down a syphon pipe, which served as a condenser, and the additional oil thus obtained was run into the same trough as before. The products from all the ovens were then allowed to flow into a large tank, from whence they were pumped into a large receiver formed of an old boiler; there the oil was allowed to settle, and the ammoniacal liquor was run off into another cistern. At Messrs. Pattinson's the pipes were 12 in. diam., and, instead of having 27 sq. ft. of cooling surface per oven, they had 70 sq. ft. per oven. At Page Bank the draft was equal to $\frac{5}{8}$ in. of water; and at Felling $\frac{3}{8}$ in. A good deal of the difference was probably due to the larger pipes, and to the gas being longer in contact with the cooling surface, and to the slower velocity of the gases. At Felling the waste gases were used to generate steam in a boiler, which supplied the engine driving the fan and pumps; but on the occasion of his visit that was disconnected in order to convey the waste gases into the bottoms of other ovens fully ignited, for the sake of burning them. At Messrs. Pattinson's, as well as at Messrs. Bell's, a large proportion of sulphate was found in the ammoniacal liquor. Many experiments had been carried out in order to ascertain the best proportion of cooling surface &c.; and therefore it would be unfair to take the average of the whole as representing the final results. However he had run out the averages, which were, oil 8·7 gall. per ton of coal, and liquor 56·8 gall. per ton, equivalent to 8·6 lbs. of sulphate. The monetary value of the results at Page Bank, taking the oil at 2*d.* per gall. (it had been variously estimated, but that was the lowest estimate), and the sulphate in the ammoniacal liquor at $1\frac{1}{2}$*d.* per lb., amounted to £23 16*s.* 8*d.* per annum per oven; and as there were 350 ovens in operation at that colliery, this would represent a very large sum if applied to all. But on the whole it would hardly be fair to take the lowest values: the result would probably lie somewhere between that which he had just given, and the value at Felling, which, taking the same prices, was £65 13*s.* per oven per annum, without counting the value of the waste gases

at all. From that they might in the first year deduct the cost of the alterations, which at Page Bank was from £8 to £10, and at Messrs. Pattinson's £15. He thought that, after having seen these ovens in operation at Page Bank, where they had converted a large quantity of coal, and after having also witnessed the results at Felling, he was fairly justified in taking those experiments as to the quality and quantity of the coke, in preference to the one experiment of which Mr. Cochrane had spoken. Judging from all the evidence, and from his own observation, he felt convinced that the invention was destined to take a prominent place amongst those which at the present time were so fruitful.

Mr. E. A. Cowper thought the diagrams, Figs. 1 and 3, Plates 25 and 27, scarcely showed the actual effect going on in the oven in the one case and in the other. If the gases were taken away from the top of the coke only, the tar produced down below partially evaporated, and passed upwards through the mass. Now tar or pitch coke was a very valuable product in itself; and if tar or bituminous coal was mixed in a coke oven where a drier coal was being used, it improved the coke wonderfully. With ordinary good coking coal, when the tar rose from below and passed upwards through the upper part of the charge, a large portion of it was carbonised into coke, and so to speak soldered the whole mass of coke together, and made it more dense: the coal, swelling at the same time, and being confined by the sides of the oven, assisted in making that hard silvery coke which was so much esteemed for blast furnaces. Unless therefore the gas had a high market value on the spot, the best thing to be done, as Mr. Bauerman had suggested, was to burn so much as was required to produce heat in the oven; because they must not lose sight of the fact that the oven was not heated by extraneous fire, but by the material within it. Something must be burned, either the coke or the gas; and unless the gas had a high value, he thought it was worth while to burn a certain portion of it to produce heat in the oven, and that that was the most economical way of proceeding. You might afterwards deal with the products, and get what you could from them, and very likely it would be economical to do so; but you must

not sacrifice the quantity of coke for that purpose. The yield of coke in the system proposed seemed to be 58½ per cent., and that was not high, though it depended greatly on the coal used. Mr. Nichol appeared to look forward to more favourable results; but he should like to see actual figures, so as to know what ground they were standing upon; also to see whether the coke was solid, hard, and heavy, with a good silvery appearance.

The late Mr. James Young had told him that he had distilled coal at as low a temperature as 600°. That was a long way below red heat, since the lowest red heat that would show even in the dark was 900°. Mr. Young had distilled as much as two-thirds of a rich coal away into by-products, liquid tar, ammoniacal liquor, and hydro-carbons, but of course very little gas; and it made most wretched coke. Mr. Samuelson had referred to the demand for sulphate of ammonia: that substance was used in large quantities in England for artificial manures; and there was also a small demand for carbonate of ammonia for making pastry rise. There were works however in the North of England where they were getting ammonia from blast-furnace gases, making 25 cwt. of sulphate of ammonia in 24 hours from two furnaces. That formed another source of supply; and therefore they must not calculate on the present prices being maintained, if those processes came into operation.

With regard to the best mode of burning the gas in the oven, which he thought was the most truly economical system, a plan had lately been brought out by Mr. Brodie Cochrane, which was roughly represented in Figs. 4 and 5, Plate 27. The air was brought in from the top at A, and went round and round through the flues BB in the roof of the oven, until it arrived at the point C, where it was allowed to issue horizontally into the gas, through two or three small apertures. The object was to produce intense combustion of the gas with the hot air, and a very high temperature, so that very little gas and air were enough to produce the heat required. The air and gas passed away to the chimney at D, so that it was not allowed to strike upon the coke; and the yield of coke was better, and the work was done more quickly. This plan had been very successful in the north; and it struck him as being an economical way of producing good coke, without wasting the coal.

Mr. Jameson, in reply, said he was sorry he should have omitted to bring samples of coke with him. He had however thought it unnecessary, inasmuch as they showed absolutely no difference in appearance from the ordinary coke made from the same coal: so much was this the case that it was found necessary to mark the samples themselves with different coloured pencils in order to distinguish which was made by the one process and which by the other. There was absolutely no difference between the one and the other, so far as he could tell. He might mention that the coke from certain ovens using his process at Page Bank had been sent over without a label to Cleveland, in order to discover if the foremen or the men at the furnaces could tell which kind of oven it came from, and they were unable to do so. He had made no actual experiments as to hardness.

Mr. Cochrane had spoken of the advantage of heating the air let in at the top of the oven. He himself thought there could be no doubt as to that being an advantage, where it could be done conveniently: but he apprehended that it might be as easily done with his oven as with the ordinary oven; therefore any objection on that score did not apply. As to the question whether it was expedient to burn gas or to burn coke, that involved another consideration. If you burned hydrogen, you required theoretically, for every lb. of gas burnt, about 36 lbs. of air; but if you used solid carbon, you required only about 12 lbs. of air. Therefore, if you were burning gas in an oven, you must necessarily pass a much larger draught through the oven, and so into the chimney, than would be required if you were using solid carbon; and every additional lb. of air enhanced the danger and loss arising from the production of carbonic oxide. Again, if the gas and air were mixed in the top of the oven, then, since burning gas had very little radiating power, the first effect of the heat was to heat the roof of the oven, which then radiated the heat on to the coke; whereas, in burning the carbon of the charge, the heat was directly applied to the exact spot where it was wanted, and therefore this was a more efficient method. If the gas was of little value at any place, there was nothing to prevent its being returned to the oven and burnt at the top, just as well as anywhere else.

As to the question of the value of the products, he did not consider himself responsible for the £75,000,000 mentioned at the end of the paper; but as he had stated the data upon which the calculation was arrived at, and as it merely gave the total value of the products as contained in all the coal, he did not think any one could complain of being in the slightest degree misled by that figure. They were dealing with 150 million tons of coal in a year, and he simply wanted to show the value of certain products contained in that coal under ordinary conditions; but he had guarded himself by saying that, cut and carve that vast total as they might, a sum would remain which it was important to get at if they could. The question of the value of gas, he admitted at once, was open to consideration. At a blast furnace it might be worth very little, but there were other places where it might be worth a great deal. In a paper by Sir William Siemens on the products of fuel, the value of gas was taken at 1*s.* per thousand feet; and it was stated that if gas could be produced at 1*s.* it might compete with coal for domestic purposes, and therefore the demand would be enormous. He had good authority therefore for taking 6*d.* as the value.

As to the quantity of products obtained from different coals, it varied immensely. Mr. Cochrane said that in his case, from New Brancepeth coal, they recovered only 3 gallons of oil and 5 lbs. of sulphate of ammonia per ton, and 58½ per cent. of coke. He knew nothing himself of that particular experiment; but during the experiments made with his process at Felling they sometimes worked with different bottoms in the oven, sometimes with a different extent of condensing pipe, sometimes with a different amount of suction; and sometimes they got absolutely no yield of oil, and at other times a large one from the same coal. The results of several of those experiments were given in Table A annexed: but he did not think that in cases of experiments a mere average was of any value: it was much better to state what might be considered a fair and reasonable yield, such as might be expected to be maintained, and perhaps any data he might have to back up the statement. No doubt there were circumstances to explain the bad result in Mr. Cochrane's case; but what they were he did not at that moment

TABLE A.—Results obtained by Jameson Coking Process at Felling Coke Ovens, 1882-3.

Name of Coal.	Hours burning.	Coal in.	Coke out. Total.	Coke out. Per cent.	Sulphate of Ammonia. Total.	Sulphate of Ammonia. Per ton.	Oil. Total.	Oil. Per ton.
	Hours.	Cwts.	Cwts.	Per cent.	Lbs.	Lbs.	Galls.	Galls.
Sherburn	71	96	59·75	62·23	15·5	3·2	22·4	4·6
Sherburn	80	96	59	61·45	13	2·7	22·8	4·7
Sherburn	83	95	57·5	60·52	17·7	3·7	21	4·4
Brancepeth Cannel ..	88	96·2	61·7	64·13	29	6	54·4	11·3
Brancepeth Cannel ..	88	95	56·7	59·68	29	6·1	62·5	13·1
Castle Eden Duff	88	93·5	45	48·12	15·07	3·2	26·44	5·6
Castle Eden Duff	88	91	48·75	53·57	25	5·4	25·7	5·6
South Tanfield	72	94	57·3	60·95	14·31	3	6·25	1·3
South Tanfield	63	95	56·25	59·21	8 2	1·7	20·7	4·3
Cambois Duff	113	94	—	—	65·52	13·9	20·7	4·4
Cambois Duff	87	94·5	32·3	34·12	83·8	17·7	37	7·8
Longhirst Best	62	91·5	49	53·55	70·93	15·5	43	9·3
Longhirst Best	88	96·2	40·3	41·89	57·47	11·9	62·3	12·9
Longhirst Small	66	98·3	25	25·43	54	10·9	38·4	7·8
Garesfield	84	95	59·3	62·42	31·56	6·6	29·12	6·1
Garesfield	84	95	61	64 21	23·36	4·9	23·75	5
Sherburn Low Main ..	88	92	60·5	65·76	13·73	3·0	26·11	5·6
Sherburn Low Main ..	88	96	61·3	63·85	25·73	5·3	23·12	4·8
Wharncliffe Silkstone	88	94	47·5	50·53	18·42	3·9	15·85	3·3
Wharncliffe Silkstone (crushed)	61	94·3	47 5	50·37	15·72	3·3	22	4·6
New Brancepeth	88	94	55	58·51	25	5·3	14·2	3
Whitburn Small	89	94	48·3	51·38	32·13	6·8	55·6	11·8
Medomsley	70	94·3	61·3	65	12	2·5	15·25	3·2
Redheugh Splint	80	94	65	69·14	17·2	3·6	18·75	4
Coxlodge Small	80	91	59	64·83	40	8·7	26 5	5·8
Totals and Averages		2359·8	1274·25	56·28	753·35	6·3	733·84	6·2

Many of these coals are not coking coals. The average yield of coke would be considerably increased if coking coals only were tabulated.

Experiments with Shales.

Name of Coal.	Hours burning.	Coal in.	Coke out. Total.	Coke out. Per cent.	Sulphate of Ammonia. Total.	Sulphate of Ammonia. Per ton.	Oil. Total.	Oil. Per ton.
Longhirst Big Seam ..	108	94·25			83·60	17·7	43·64	9·2
Longhirst Little Seam	108	96			68·19	14·2	30·30	6·3
Longhirst Grey Band	88	98			77·80	15·8	23·79	4·8
Totals and Averages		288·25			229·59	15·9	97·73	6·7

TABLE B.

Analysis of Gases obtained from Coke Ovens at Felling by Jameson Coking Process.

Name of Coal.	No. of hours oven had gone.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Hydrogen.	Nitrogen.
	Hours.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Longhirst Small ..	44	4·98	22·22	6·13	20·42	46·25
Sherburn	46	4·48	23·88	0·75	25·00	45·89
South Tanfield	48	2·30	20·00	3·43	34·60	39·69
Wharncliffe	49	3·47	19·09	5·45	26·21	45·78
Baxenden	49	2·44	27·50	1·16	21·08	47·82
Castle Eden Duff ..	40	4·31	25·10	3·14	23·70	43·75
Widdrington	48	7·09	23·23	5·51	23·23	40·94
Burradon Small ..	48	4·74	30·00	0·80	39·13	25·33

TABLE C.

Analysis of Crude Oil obtained by Jameson Coking Process.

Description of Oil.	Bell Brothers.	Felling.
	Per Cent.	Per Cent.
Light Oil	3¼	6
Burning Oil	49	40
Lubricating Oil..............................	8	8
Wax Oil	26¼	31½
Grease Oil	1	2
Pitch; and loss	12½	12½
	100	100

know.* It was stated by Mr. Samuelson that the paper condemned the Simon-Carvès process, but he had no intention of condemning any process whatever, and so he had said at the end of the paper, p. 287. In regard to the Simon-Carvès process there certainly was the disadvantage that it was necessary to transmit a large quantity of heat through a bad conductor of considerable thickness; and it was important to reduce that difficulty, and to get the heat applied as closely and directly as possible to the place where it was wanted. In regard to the percentage of coke, he must admit that the Simon-Carvès process gave a much larger percentage than the ordinary process or his own; and what they had to do was to balance the advantages of one process against those of another. He did not come forward to recommend one plan in preference to another; but he asked that the merits and the disadvantages of each should be fairly balanced.

Something had been said about the withdrawal of gas being detrimental to the coke; and Mr. Cowper had said the same as to tar and pitch. In any process whatever of making coke the gas must pass away, but not necessarily the pitch: it was important to bear in mind that his process did not really take away the pitch. In Fig. 1, Plate 25, there was shown ordinary coal near the bottom, and absolutely incandescent coke at the top; and between the two there was a more or less soft band, in which pitch was forming and distilling continually. That pitch, he believed, got set in the coke before it could become absolutely incandescent, and was then gradually distilled or boiled, as in the process of distilling anthracine, until nothing further would come from it: and what finally remained, after sustaining the great heat, was pitch-coke. The oil extracted contained scarcely any pitch.

Mr. Cochrane had spoken of air passing into the oven; and there must of necessity be a large quantity of air introduced in order to

* Mr. Pattinson has since explained that the charge of New Brancepeth coal burnt very hot, and was ready for withdrawal from the oven at the end of 72 hours; but owing to the coal for the next experiment not being accessible at the time, the coke remained in the oven 16 hours longer, during which time of course some waste occurred.

get the heat required. There must be combustion in some form or other: either the Simon-Carvès plan must be used, where air was mixed with gas and supplied in flues outside, or else combustion must be produced in the solid or gaseous contents of the oven itself. His own opinion was that, the nearer you could bring the sphere of combustion to the place where the heat was wanted, the better.

With regard to making the brick-work of the oven bottom tight, he did not anticipate any great difficulty with that. By putting a supply of tar into the oven on its conversion, and allowing it to soak down into the pores and joints of the brick-work, a species of seal was produced, which made a very good barrier against the introduction of air. No doubt they always did admit a certain quantity of air. They sometimes had gas containing 80 per cent. of nitrogen, showing a large amount of leakage going on in the oven bottom or suction pipes; but they often got good gas containing only 30 per cent. showing that in proper conditions this leakage was manageable.

The PRESIDENT said that, although the subject brought before them was not perhaps strictly a mechanical one, it was one of very great importance to engineers, and it had provoked a very interesting discussion. He had no doubt that Mr. Jameson would be good enough to send up comparative samples of coke to the Institution, where they might be seen by any Members who took an interest in the matter.*

* Several samples of the coke have since been sent to London by Mr. Jameson, and are now in possession of the Institution.

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1883.

The Summer Meeting of the Institution was held in Belgium, commencing at Liége, on Monday, 23rd July 1883, 8.30 p.m., by a reception at the Hotel de Ville.

The Members, headed by the President, Percy G. B. Westmacott, Esq., assembled in the Town Hall (Salle des Pas Perdus), where they were met by M. L. Trasenster, President of the Association of Engineers from the University of Liége. After a few words of welcome, addressed to the President, M. Trasenster led the way to the upper hall (Salle des Mariages), where they were received by the Bourgmestre, M. Mottard, and by several of the principal Echevins, or Town Councillors.

M. Mottard welcomed the Institution in the following words:—

Sir,—It is a great honour which your Institution has conferred upon the city of Liége by choosing this as the locality for your scientific holiday of the present year. We feel touched by this mark of appreciation, and render you our most sincere thanks.

Our fellow-citizens have not forgotten the cordial reception which on many occasions they have received in England, notably on that of the rifle match at Wimbledon. Hence during your sojourn at Liége they will strive to evince to you their grateful remembrance of the past, and their warm sympathy in the present.

Welcome then, gentlemen, to the city of Liége.

The President said he had the honour of thanking the Mayor, in the name of the members of the Institution of Mechanical Engineers, for the very kind and hearty reception that had been

given to them in the ancient and thriving city of Liége. He was quite sure that they would all very much enjoy their visit. It would certainly be a profitable one to themselves, and he hoped that they would also leave kindly recollections behind them in the minds of their hosts. As, by the kind permission of the Mayor, he was about to read an address, in which he should touch upon certain points in connection with their visit to Belgium, he would not now take up more of their time; but he desired to thank the Mayor again and again for the very kind and hearty welcome he had accorded to the Institution.

The PRESIDENT then read his annual Address.

M. L. TRASENSTER proposed a vote of thanks to the President for his interesting address; and, speaking on behalf of the Mayor, hoped that a copy would be presented to the city, in order to be preserved in its archives as a souvenir of the visit of the Institution to Liége.

Mr. T. R. CRAMPTON said that, in seconding the vote of thanks to the President, he felt that they could not thank a better man. He had had the pleasure of being connected with him intimately for some time, and he had for many years known his senior partner, Sir William Armstrong; and he believed that no such firm as theirs existed in the world—not even in Belgium. At the same time he had also known Messrs. Cockerill's works for many years, and in those works they had been almost running neck and neck with their friends at Elswick. He seconded the vote of thanks with the greatest pleasure; and in conclusion he trusted that they might have the opportunity at some future time of meeting Belgian engineers in England, so that they might be able to return the high compliment which had been paid to them that day.

The vote of thanks was passed by acclamation.

The PRESIDENT thanked the members for the kind and hearty manner in which they had responded to the vote of thanks to himself.

The Meeting was then adjourned till the following day.

The ADJOURNED MEETING of the Institution was held in the Hall of the Société d'Émulation, Liége, on Tuesday 24th July 1883, at half-past eight o'clock, a.m.; PERCY G. B. WESTMACOTT, Esq., President, in the chair.

The Minutes of the previous meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and that the following candidates had been found to be duly elected:—

MEMBERS.

WILLIAM SUTHERLAND ABBOTT, . . .	Maceio, Brazil.
EDWIN CLERK ALLAM, ...	Romford.
HARRY HAYWOOD BARRAS, ...	Pernambuco.
EDWARD PHILP BASTIN, ...	West Drayton.
GEORGE BODDEN, ...	Oldham.
HENRY CROFT, ...	Boisfort, U.S.
CHARLES D'ALBERT, ...	St. Denis.
JAMES GILBERT DAW, ...	Llanelly.
WILLIAM FREDERICK DENNIS, . . .	London.
FRANK WESLEY DICK, ...	Glasgow.
GEORGE FLETCHER, ...	Derby.
PERCY CARLYLE GILCHRIST, ...	London.
FREDERICK HART, ...	Croydon.
JOHN BAILLIE HENDERSON, ...	Brisbane.
WILLIAM HOOTON, ...	Nottingham.
EDWARD JORDAN, ...	Cardiff.
WILLIAM S. LAYCOCK, ...	Sheffield.
JOHN LENNOX, ...	London.
JOSEPH LESLIE, ...	Calcutta.
ROBERT PATRICK TREDENNICK LOGAN, .	Dundalk.
PERCY JOHN NEATE, ...	Rochester.
GIOVANNI PATTISON, ...	Naples.
EDWARD PILLOW, ...	Crewe.
EDGAR PHILIP RATHBONE, ...	London.

GEORGE RYDER, ...	Bolton.
EUGÈNE SADOINE, ...	Seraing.
WILLIAM TAYLOR, ...	Nottingham.
FRIEDRICH WECK, ...	Donnington.
HENRY E. WHARTON, ...	Nottingham.
EDWARD LEADER WILLIAMS, . . .	Manchester.
RICHARD WILLIAMSON, ...	Workington.
ROBERT WILSON, ...	Patricroft.

ASSOCIATES.

Capt. CHARLES FAIRHOLME, R.N., . .	London.
ROBERT S. WILLIAMSON, ...	Hednesford.

GRADUATES.

PERCY VAVASSEUR APPLEBY, . . .	London.
WILLIAM STANWAY BOOTH, ...	Manchester.
FREDERICK McDAKIN CLENCH, . . .	Lincoln.
HENRY JOHN FRANKLIN COWAN, . .	Lincoln.
JOHN FREDERICK O'CONNOR, ...	London.
HENRY ARMSTRONG WESTMACOTT, . .	Newcastle-on-Tyne.

The PRESIDENT said he had a very pleasant duty to perform, and one which he was sure would give very great satisfaction to the Members. It was to announce that the Council had that day nominated M. L. Trasenster an Honorary Life Member of the Institution. M. Trasenster was President of the Association of Engineers from Liége University, and as such he had sent to the Institution the invitation by which they were then profiting. He was also Rector of the University, in which for very many years he had held the important chair of Mining. He had published a number of valuable papers on matters connected with science, and he held a most prominent position in Belgium, both as a scientific and as a public man. He need not say that the Institution would consider itself greatly honoured if M. Trasenster would accept the position they offered him.

M. TRASENSTER said he was greatly honoured and touched by the announcement which had just been made by the President. To be an Honorary Life Member of an Institution so powerful, and containing so many men of genius, was an honour beyond his merits; he nevertheless accepted it because he owed it to the position he held as President of the Association of Engineers from the University of Liége, which Association would itself be honoured by his nomination; and also to his position in connection with the teaching of science in that University. He thanked the members very cordially and sincerely for the reception they had given to the too flattering declaration made by the President. He would try to the best of his ability to justify it, or rather to show himself worthy of it. He thanked them again with all his heart.

The PRESIDENT said that, having received a command from His Majesty the King of the Belgians to wait on him that morning at the Palace of Laeken, as a mark of honour to the Institution, he was compelled to vacate the chair; and he called on Mr. CHARLES COCHRANE, Vice-President, to take his place.

The following paper was then read:—

On the History of the Iron and Coal Industries in the Liége district; by M. Édouard de Laveleye, of Liége.

The CHAIRMAN said M. de Laveleye's very interesting historical paper was of a kind not calling for discussion; but he was sure they would all join in thanking the author for the able way in which he had brought before them the advances that had been made in Belgium, and for his congratulations and hopes for the future with reference to England.

The vote of thanks was carried by acclamation.

The following paper was then read and discussed:—

On the Manufacture of Zinc in Belgium; by M. St. Paul de Sinçay, Managing Director of the Vieille Montagne Zinc Company.

On the motion of the Chairman, a vote of thanks was unanimously passed to M. St. Paul de Sinçay for his paper.

At 11 A.M. the Meeting was adjourned till the following day.

The ADJOURNED MEETING of the Institution was held in the Hall of the Société d'Émulation, Liége, on Wednesday 25th July 1883, at half-past eight o'clock, a.m.; PERCY G. B. WESTMACOTT, Esq., President, in the chair.

The following paper was read and discussed:—

On the Manufacture of Sugar from Beet-root; by M. A. Melin, of Wanze.

M. DE LAVELEYE, on behalf of M. Melin, exhibited specimens of the beet-root itself, whole and after cutting, of the knives used for cutting, and of the manufacture in all its stages, from the raw juice to the refined sugar and molasses.

The PRESIDENT said they had just listened to one of the most exhaustive papers ever brought before the Institution; in fact it appeared so exhaustive that it would be exceedingly difficult to get up a discussion upon it. The author had treated the subject, of which he was a thorough master, so fully, and in such an admirable manner, that there appeared to be very little that any one else could find to say upon it.

He proposed a hearty vote of thanks to M. Melin, which was carried unanimously.

The following papers were then read and discussed:—

On the Application of Electricity to the Working of Coal Mines; by Mr. Alan C. Bagot, of London.

On Compound Locomotive Engines; by Mr. Francis W. Webb, of Crewe, Vice-President.

On the Construction and Working of the St. Gothard Railway; by Herr E. Wendelstein, of Lucerne.

On the motion of the President, votes of thanks were unanimously passed to the authors for their papers.

The PRESIDENT proposed the following votes of thanks, which were carried by acclamation:—

To the Mayor of Liége, the Mayor of Antwerp, M. L. Trasenster, President of the Association of Engineers from the University of Liége, and to the Reception Committee, for their kind reception of the Members, and for the arrangements made for the Meeting and Excursions, both at Liége and Antwerp.

To the Société d'Émulation, for their kindness in granting the use of their rooms for the Meeting.

To the numerous Firms in Belgium, who have so handsomely thrown open their Works to the visit of the Members.

To M. Sadoine, to the Engineers of Liége University, to M. St. Paul de Sinçay, to the Verviers Chamber of Commerce, to M. d'Andrimont, to M. Guinotte, and to the other gentlemen throughout Belgium who are so hospitably and liberally entertaining the Members during the Meeting.

To the Belgian, French, and English Railway Companies, and to the Liége Tramway and Steamer Companies, who have kindly granted special facilities to the Members for travelling to and from Liége, and for the various Excursions.

To the Honorary Local Secretaries, M. Édouard de Laveleye and Mr. A. W. W. Willmott, for their very active and valuable services in maturing all the arrangements for ensuring the success of the Meeting.

The Meeting was then adjourned to Antwerp, on Friday 27th July.

The ADJOURNED MEETING of the Institution was held at the Hotel de Ville, Antwerp, on Friday 27th July 1883, at nine o'clock, a.m.; PERCY G. B. WESTMACOTT, Esq., President, in the chair. The Members were received in the Salle des Lys, by the Bourgmestre of Antwerp, M. Léopold de Wael, and by several members of the municipality.

M. de Wael said that, in the name of the Communal Administration of Antwerp, of which he had the honour to be the head, he had great pleasure in giving a hearty welcome to the members of the Institution of Mechanical Engineers, including as they did so many men of high scientific intelligence in the great country of England. The members of that Institution, who had witnessed in their own country the execution of so many works of all kinds, intended to promote the welfare of humanity, would be able to appreciate the efforts that were being made in Belgium to maintain the position of that country in regard to scientific progress. He hoped that the members would retain a pleasant recollection of their visit to Belgium. Everything would be done by the authorities at Antwerp to render their sojourn in the city as useful as agreeable. He was happy to be surrounded by men of intelligence and devotion, who would do all that was possible to make themselves useful to the members. He begged to present to them M. Matthys, engineer of the Ponts et Chaussées, who was charged with the direction of maritime affairs, and M. Royers, engineer of the city; both of whom would be happy to place themselves at the disposal of the members. He also presented M. Hersent, one of the contractors for the new harbour works, and M. Coiseau, the director of the works. All those gentlemen (as would he himself, if it were possible consistently with his duties) would do everything that could be done in welcoming the members of the Institution. He hoped that the sun, of which they had lately seen but little, would give them the benefit of his presence during their visit.

The President said that, on behalf of the members of the Institution of Mechanical Engineers of England, he had the honour of returning hearty thanks for the very cordial welcome they had received in the ancient and renowned city of Antwerp. He could assure the Mayor that they thoroughly reciprocated the kind sentiments which had been expressed to them, with reference to their country and to their profession. They had been for some days past travelling over the interesting country of Belgium, and had been received with a cordial welcome in many of the chief

centres of Belgian industry. In fact their progress had been like that of a victorious army. That was not perhaps an inapt illustration; for he thought they were in fact the representatives of a victorious army—he did not refer to Englishmen only, but to the cosmopolitan body of engineers and practical men of science, who were the pioneers of progress, peace, and prosperity, who opened out the rich treasures of the earth, and were covering her waste places with works of industry. The city of Antwerp itself was, he ventured to think, greatly beholden to the engineer. Looking back a few years, and remembering what Antwerp was, and then looking at its present condition as the first port of the Continent; remembering the magnificent river wall (which many of his hearers had already seen), the docks, the railways, and the electric and other appliances in the town, it was not, he thought, too much to say that Antwerp was beholden to the engineer. It was also interesting to look forward to what Antwerp was destined to be. For it could not stand still, it must either go forward or decline; and they had seen enough of the spirit and enterprise of her citizens to feel sure which of those alternatives she intended to follow. It remained only for him to thank their Belgian friends again most heartily for the cordial welcome that had been given to them, and to thank beforehand those gentlemen who had placed their services at their disposal on that day. As Englishmen they were not afraid of a little rain. They were accustomed to take many of their pleasures, and do a great deal of their work, in rain and without sunshine; and it would take a great deal of rain to spoil the spirits of an Englishman.

The Members then withdrew to the adjoining hall, where the President took the chair, and the following paper was read:—

Description of the New Harbour Works at Antwerp; by M. G. A. Royers, Engineer to the Municipality of Antwerp.

The President said that, before calling upon the members to give M. Royers a hearty vote of thanks, he was requested to state that M. Royers would have been happy to answer any questions which

the members might put to him upon the subject of the works he had so admirably described; but as time pressed, any such discussion was then impossible. M. Royers was going to accompany the members to the works, and would be happy there to answer any questions. It was now his pleasing duty—a duty which could not but be pleasing to any one in his position—to call upon them to give a most hearty vote of thanks to M. Royers; and he hoped they would allow him on that occasion to indulge in a little personality. It was particularly pleasing to him that he should be the President of the Institution at this time, and that it should have fallen to his lot to have the pleasure of calling upon them to give a hearty vote of thanks to M. Royers, because he had had the privilege and pleasure of knowing him ever since his appointment to the important position he held. During that time he hoped he had gained M. Royers' friendship, as M. Royers had certainly gained his. Knowing him as he did, he would only say that Antwerp was to be congratulated in having the services of such a man.

The vote of thanks was carried by acclamation.

The PRESIDENT desired to call attention to a number of engravings of the floating cofferdam, which had been distributed to the members, having been presented for that purpose by the editor of 'Engineering,' whom he was sure they would wish to thank for his attention.

The Meeting then terminated.

ADDRESS OF THE PRESIDENT.

When at the birth of our Institution, in the year 1847, the chair was occupied for the first time by George Stephenson, we may question whether even the genius of that large-minded man carried his fertile imagination so far as to picture the enormous extension that would take place in railroads within a few years, not only in his own country but all over the world; covering rapidly some favoured portions of the earth, containing coal and iron, with a perfect network of rails, and sowing and reaping industries which would call forth a host of engineers to work out and to conduct. And perhaps that powerful mind—whose manhood doubtless was stirred by events which made the hearts of England and Belgium throb in unison, in their determination to uphold and hand down to posterity, as the richest of all gifts and legacies, that true liberty which is the very life of industry and peace—even that mind would hardly contemplate such a scene as is enacted in Liége this day—a little army of British Engineers, sent forth from his old Institution, by invitation of our old ally, this time happily to meet on a field of industry, whose increasing richness is largely due to the development of his inventions and his work.

This Institution has never before travelled out of England, except for the two Exhibitions at Paris in 1867 and 1878. They have now accepted the invitation given them by the Municipalities of Liége and Antwerp, by the Association of Engineers of the University of Liége, and by a large number of the foremost and most influential manufacturers of the country, to visit Belgium—a land remarkable not only for its rapid industrial development of late years, but for the remote period at which those industries were established, and especially industries most interesting to

engineers, such as those relating to iron and to coal. It seems probable that we are indebted to Belgians for two most important strides in the manufacture of iron and steel, namely the blast furnace and the cementation process. The reasons for this belief are set forth in an interesting paper shortly to be read by our able Honorary Local Secretary, M. Édouard de Laveleye. In this paper the histories of the iron and coal trades in Belgium are so fully and clearly treated, that any remarks on my part, such as I might otherwise have ventured to make, would be wholly superfluous; and I will not therefore dwell longer on that topic.

As regards the present development of Belgian industry, we hope to learn much in the course of the present week; and that there is much to be learnt I am well aware. There are several important points in which the industrial supremacy of Belgium is unquestioned. On two of these we shall be fully enlightened to-morrow morning. I allude to the mining and working of zinc, as set forth in a masterly sketch by M. St. Paul de Sinçay, and to the manufacture of sugar from beetroot, as most exhaustively treated by M. Melin.

Another point to which I may direct attention is the wider and more artistic use of iron in buildings. Belgian architects have been bold and skilful in treating iron as a material for construction, while as to artistic manipulation, it is evident that they still feel the influence of their great artists of former days.

But the representative of an Institution like ours, when thus meeting a body of his professional brethren in a foreign country, may be pardoned if he reviews with some degree of pride the position now attained by the engineer. For if the inventive skill of the engineer had not provided those appliances, on which all trades are dependent for cheap and rapid production, what, may I ask, would have been the result of the great increase in population which has taken place in recent times? The nations of Europe would be like the hordes of barbarians in the early ages of Christianity, who were compelled to over-run neighbouring countries with fire and sword, in order to provide an outlet for their own population. But the advances of commerce and industry, consequent upon the

invention of mechanical processes and appliances, have enabled nations both to find work for their population at home, and to send their children cheaply and readily to unoccupied countries, where they are at once able to utilise and to subsist upon the boundless resources which those countries contain. A great debt is therefore due to the engineer. It may well be questioned whether the world does not owe more to George Stephenson, as the founder of the modern system of speedy transport, than to any of the great public men she has produced. Nor is the advantage one which relates to money only; it is a question of peace and prosperity, for the more people are occupied in peaceful industries, the less risk there is that they will be inclined to engage in devastating wars.

There are other advantages following in the train of that immense extension of engineering progress which has taken place all over the world. Among these may be mentioned the impetus given thereby to education. Whilst the mere tilling of the land can be followed out by a man totally devoid of education, this becomes impossible if he has to exercise arts requiring skilful training. Belgium has been especially ready to recognise this fact, and the institutions she has established for the education of the working classes are justly considered a model for the rest of Europe.

Again, engineering brings all other sciences into play. Chemical or physical discoveries, such as those of Faraday, would be of little practical use if engineers were not ready with mechanical appliances to carry them out, and make them commercially successful in the way best suited to each. A special illustration of this fact is to be found in the varied applications of electricity to practical purposes, in which the telegraph, whether by land or sea, will ever hold the foremost place. With regard to the latter, in particular, my hearers will be aware that the development of the submarine cable, with all the machinery necessary for its construction, laying, maintenance, and repair, is largely due to mechanical engineers; and I may add that the first submarine cable, still in use, was laid down between Dover and Calais, in the year 1851, by our Vice-President Mr. Crampton. One of the latest instances of the same character is the application of electricity to the lighting and working of mines—a

subject which will be dealt with in a paper to be read before this meeting by our member Mr. Alan C. Bagot.

The result of all this is a continual race, as it were, between the engineers of the same country, and also between the engineers of different countries, in the invention of new and the improvement of existing appliances. The keen and continual attention thus bestowed upon the work to be done, and the means of doing it, has led engineers in general to regard speed of production as one of the first elements of success. There is indeed a proverb, "more haste, less speed;" but this, though true of human labour, which ceases to be accurate when forced beyond a certain rate, does not hold good of mechanical processes. Generally it may be said that rapidity of working not only reduces cost, but improves the result; and also confers great benefits from the way in which it brings out and perfects the highest qualities of the engineer. To be able to do a thing leisurely and quietly, simply requires the rudest materials and the rudest workmanship; but if work is to be done quickly, or the appliance made to move quickly, the case alters. Mechanical energy increases as the square of the speed; and so it may be said that the mental energy and skill required to carry on work increase also at something like the square of the speed with which that work is performed. The materials used must be far stronger and far finer; everything must be well proportioned and balanced; there must be the most perfect arrangement in each structure and in every part of a structure; the most perfect workmanship in the fitting of those parts together; and thus we may almost reverse the proverb, and say of mechanical processes, "The higher the speed, the better the work."

This view opens out so wide a field for contemplation that to traverse it even rapidly would require rather a volume than a paper. All that can be done at present is to give a very few obvious illustrations of the subject. Take for instance the steam-ship with her engines and accessories, more especially the modern ship of war. There is scarcely any structure which requires so much care and skill, both in its design and execution; not only does

it involve all the problems which occur in erecting steam machinery on land, but in addition the vessel has to contend against the heavy and uncertain strains due to wave action during the roughest weather. Hence all parts of the structure, and especially the engines and boilers, should be so designed and constructed, and the materials so selected, that their weight may be reduced to the lowest point. Every increment of speed attempted to be given is accompanied with complex questions of increasing difficulty, taxing the skill and powers of the engineer to the uttermost. The development of the compound condensing engine, for instance, is largely due to the marine engineer, who was driven by necessity to study most closely the economy of fuel, in order thereby to gain speed.

The torpedo boat is an excellent example of the advance towards high speeds, and shows what can be accomplished by studying lightness and strength in combination. In running at 22½ knots an hour, an engine with cylinders of 16 in. stroke will make 480 revolutions per minute, which gives 1280 feet per minute for piston speed; and it is remarked that engines running at that high rate work much more smoothly than at slower speeds, and that the difficulty of lubrication diminishes as the speed increases. Doubtless the experiments on Friction which are now being conducted by this Institution will throw light upon this subject.

An important experiment in high speed in light vessels, which will doubtless be watched with much interest, is now being carried out. Mr. Loftus Perkins is building a steel vessel with a screw at each end: she is 150 feet long; her boiler pressure will be about 800 lbs. per sq. in.; and she has a four-cylinder compound condensing engine of 800 HP. working on to a single crank, and making from 400 to 500 revolutions per minute. When this vessel is laden with 300 passengers, her total weight will not much exceed 150 tons. Should this experiment be successful, it will materially advance the solution of the problem, how to put the largest possible amount of propelling power into a vessel, and so to drive her at the highest possible speed.

Again, in touching upon speeds, the mind naturally reverts to

railway travelling. Here however it would seem as if for the present we had reached a maximum. It is surprising how soon the speed of the locomotive was brought up to something approaching its present limit. George Stephenson was laughed at in 1825 for maintaining that trains would be drawn by a locomotive at twelve miles an hour; but the Rocket herself attained a speed of twenty-nine miles an hour at the Rainhill competition in 1829, and long afterwards ran four miles in four-and-a-half minutes. In 1834 the average speed of trains on the Liverpool and Manchester railway was twenty miles an hour; in 1838 it was twenty-five miles an hour. But by 1840 there were engines on the Great Western Railway capable of running fifty miles an hour with a train and eighty miles an hour without. In 1841 we find Stephenson himself ranged on the side of caution, and suggesting that forty miles an hour should be the highest regular speed for trains. In 1851 Mr. Crampton, who had already in 1849 inaugurated the express service of the Continent on the Northern Railway of France, conveyed a train 20 miles in 19 minutes, 4 miles in the journey being at the rate of 75 miles an hour. Thus it is a remarkable fact that the highest speed at which locomotives run in ordinary practice scarcely seems to have been raised during the last thirty years; on the other hand, the weight of the trains has been perhaps doubled. Although the average running time of express trains has in many cases been improved, this has been almost entirely due to their making fewer stoppages. At the same time the speed occasionally attained is very great. Engines on some of our principal lines have repeatedly run fifteen miles in twelve minutes, or at a speed of seventy-five miles an hour, and express trains run regularly at fifty-three miles an hour. It does not follow however that there is never to be any increase in the speed of trains, and it seems a point well worth consideration in what way the time of transit between important centres of trade can be shortened.

What are the causes which have tended to prevent any improvement in this particular? In the first place it may be said that the permanent way would suffer seriously by further increase in speed; but this could surely be overcome in time by improving the

permanent way itself, which also remains very much in the same condition and of the same construction as it was twenty-five years ago. Again, it may be said that the running at a higher speed would require more powerful engines, and hence that trains now worked by a single engine would require two, or would have to be split up into two trains at a great increase in running expenses. This however assumes that it is not possible so to improve the engine that it shall be able to exert a considerably higher power without an inadmissible increase in weight. By utilising a larger part of the total weight of the engine as adhesion weight it would be easy to obtain the amount of adhesion required for the increased tractive force; and for this purpose Mr. Webb's compound locomotive (to be described by the author in a paper he has prepared for this meeting), which enables the number of driving wheels to be increased without the use of coupling-rods, appears to merit particular attention.

Another point in which improvement may possibly arise in the future should be noticed. On the Russian railways, where both coal and wood are dear, the burning of petroleum has now taken a practical form. Our member, Mr. Thomas Urquhart, has been very successful in this direction, and is now running locomotives regularly which use only petroleum refuse, and which show a marked economy over coal or wood. To test the point, he prepared three locomotives of exactly the same type, and started them on successive days under exactly similar conditions of weather, train, and section of road. The trips were made both ways, and the results per verst, including fuel required in lighting up, were as follows:—

Anthracite, 52·9 Russian lbs., cost . . .	26·35 copecks.
Wood, 0·0107 cubic sajene, cost . . .	23·54 „
Petroleum-refuse, 27·36 Russian lbs., cost .	11·64 „

There is thus in this instance an economy of at least 50 per cent. on the side of petroleum, the boiler pressure being from 120 lbs. to 130 lbs. and the gross load over 400 tons. At the same time the weight of fuel used, as against coal, is diminished by about 50 per cent., which is a most important consideration.

Although petroleum is scarcely a product of Western Europe, we

have to notice on the other hand the progress which has lately been made in the extraction of oil as a waste product from coal, &c. Mr. Jameson has extracted as much as nine gallons per ton from mere shale. It is suggested that markets for such oil will be difficult to find; but it seems allowable to hazard the idea that we may hereafter see our locomotives, even in England, running with oil fuel, which would be at once much lighter and much more easily renewed than the coal which is used at present, and would get rid of the intolerable nuisance of smoke and dirt. There might in fact be an oil tank and a water tank side by side at every stopping station, and the engine would replenish her store of fuel at the same time as her store of water.

For a special case where speed is not only a means of doing work well, but an indispensable condition of doing the work at all, we may take the construction of long tunnels. As to this we have the advantage of two very valuable papers on the St. Gothard Railway, prepared by Herr Wendelstein of Lucerne—one of them already published in our Proceedings, the other to be read at the present meeting. The piercing of a tunnel nine miles in length through the main chain of the Alps would be a financial if not a physical impossibility, but for the enormously increased speed of working which has been offered us by the invention of dynamite on the one hand and of rock-drilling machines on the other. As a result, we find that the St. Gothard tunnel, nine miles long, was completed in nine years; while the Arlberg tunnel, begun with the advantage of the St. Gothard experience, will be completed, it is confidently expected, at a rate 50 per cent. quicker. As regards the driving of the leading heading (the crucial point in tunnel work) the rate at the Laveno tunnel is stated to have reached 19 ft. per diem. Even in the hard granite of the Pfaffensprüng tunnel on the St. Gothard the rate of advance, with the Brandt hydraulic drill, reached a maximum in May, 1880, of 13 ft. per diem. At the Arlberg tunnel I believe that still better results have since been attained with the same machine.

Another point in which speed and perfection of workmanship have gone hand in hand is the important industry connected with textile fabrics. When Arkwright first brought his inventive

mind and mechanical skill to bear upon this subject, the tools he had to work with were rude compared with the tools of the present day, and could not produce the accurate work now attainable; and therefore the speed at which he was able to drive his spindles was not remarkable. But our member Mr. John Dodd, of Messrs. Platt Bros., informs me that the average speed of mule spindles at Oldham, in new mills with new machinery, and spinning No. 32 yarn from American cotton, is about 8500 revolutions per minute; whilst speeds as high as 9500 or even 10,000 revolutions have been attained. When we consider the delicate nature of the material under treatment, the disastrous result of the slightest hitch or unevenness in working, and the perfection of mechanism required to bring up a multitude of spindles to such a speed from that of the comparatively slow main shaft of the mill, we may give every credit to the constructive skill which has achieved such a result. In woollen mills (of which we hope to see some excellent examples at Verviers on Thursday next) the speed is 4000 revolutions per minute. The progress made here has not been so great; mainly, in Mr. Dodd's opinion, from wood being still adhered to as the material for the bobbins. Here therefore is a case where improved material may yet produce improved speeds; but with cotton Mr. Dodd considers that the extreme possibilities as to speed have been very nearly attained. The limit however is imposed by the feebleness of the material, not by any lack of skill or enterprise on the part of the engineer. "If higher speeds were required," says Mr. Dodd, and I fully believe him, "we could make spindles which would be equal to the demand."

The construction of modern artillery, and with still greater justice the methods of employing it, may properly be brought under the scope of this address. I doubt whether of late years any mechanical appliances or arrangements have given greater impetus to skilful work and to the improvement of materials, especially of steel. Twenty-five years ago the largest piece of ordnance in use was a gun weighing $4\frac{3}{4}$ tons, firing a maximum charge of about $15\frac{1}{2}$ lbs. of powder with a ball of 66 lbs. weight, and made of cast iron, a treacherous

material for such purposes. We have now guns built up on well understood mechanical principles, of the most trustworthy and suitable material known, weighing 100 tons, and firing charges of 772 lbs. of powder with shells of 2000 lbs. Already considerable experience has been obtained with guns of this weight. No fewer than fourteen have been issued from the Elswick Works, and several more are in the course of construction.

Perhaps the most interesting feature in these formidable pieces of ordnance is the ease, rapidity, and noiselessness with which they are worked. It is of course impossible that such ponderous pieces could be brought into practical use without the aid of some mechanical appliances; but it is scarcely an exaggeration to say that nothing can work with greater precision and ease, and be better under control, than the hydraulic machinery employed for opening and closing the breech of the gun, ramming home the charge, elevating or depressing, running in or out, and training the gun with accuracy on a given object. Two men working levers perform all these operations, and they together with the machinery are under complete protection from an enemy's fire.

The projectile when fired has an energy imparted to it equal to nearly 48,450 ft.-tons; yet the gun is under such entire control that its recoil, due to this enormous force, is completely absorbed in a distance little exceeding 3 ft., without undue strain to any part of the mechanism. When it is remembered that the internal dimensions of the costly turrets in which guns of this size are ordinarily mounted depend mainly upon the space allowed for recoil, it is clear that it is of very great importance to reduce this space to a minimum.

On the Continent the progress in artillery science has not reached so high a point. The largest wrought gun yet made out of England weighs 70 to 71 tons, and I believe I am correct in saying that only a single specimen of this gun exists. It has a power of about two-thirds that of the Elswick gun, with something more than two-thirds its weight. The largest guns hitherto made in the Royal Gun Factory at Woolwich are of 80 tons, of which, I think, seven have been completed. It must not be supposed that the

limit in weight and power of guns has been attained. Up to the present time the Elswick 100-ton guns have been considered sufficiently powerful for the attack of any armour-clads afloat or likely soon to be built, or for any existing coast-batteries; but there would be little difficulty in constructing guns of greatly increased power, and of working them with as much ease as at present.

In a former address I attempted to point out the enormous gain to a country, having a sea coast, in enlarging to the utmost its powers and facilities for water traffic, and especially in providing means for docking and for loading and discharging costly steamers with rapidity. We shall have an opportunity of seeing what has been done in this direction at Antwerp, and its results are described in an able and interesting paper kindly prepared by M. G. A. Royers for this meeting.

The fact which lies at the bottom of the whole of these results is of course this, that the attainment of a high speed requires a more perfect machine, and with a more perfect machine more perfect work is turned out. In conclusion, it should be remembered that high speed, especially speed of rotation, is almost necessary to give perfect accuracy and steadiness to motion, as in the case of an ordinary spinning top, of a gyroscope, and again of the ingenious centrifugal machines now in use for separating cream, &c. The speeds which we find in Nature are beyond all conception high, and her operations under those speeds are absolutely true and perfect. We cannot hope to vie with Nature even to an infinitesimal fraction of her powers of speed and accuracy; but in this, as in many other great lessons taught by her, we see the direction in which we must travel in our efforts towards the perfection of work.

Finally, it is unfortunately a necessity that nations should still provide themselves with materials for war; and engineers have to devote their minds to the perfecting of such materials. It does not seem impossible that projectiles may be gradually developed, of such precision and devastating power as to make the existence of life within a certain range well nigh impossible. Were this accomplished, it is clear that nations would hesitate more and more before rushing

into a war so destructive; and even if they did so, its rapid termination would unquestionably go far to diminish the various miseries which war always brings in its train. Hence it may not unfairly be said that the attention and skill given to the arts of war are really our best warrant for the continuance of peace.

ON THE HISTORY OF THE IRON AND COAL INDUSTRIES IN THE LIÉGE DISTRICT.

By M. Édouard de Laveleye, of Liége.

I. The Iron Trade.

It is difficult to say exactly how the art of working Iron originated in those provinces of ancient Belgium, which have since become known as the district of Liége (see District Map, Plate 29).

It is certain that Asia was the cradle of iron working, and it is possible that the Eburones and the Nervii, the ancestors of the present Belgians, brought with them from the Euxine, where they had their origin, secrets which had been already known for ages in that district. However this may be, it is almost certain that when Cæsar arrived in Gaul he found among the tribes he subjugated a knowledge of the art of transforming the ores of iron into a metal which they used for different purposes, especially that of arms. The discovery, in 1870, of ancient furnaces still filled with materials, at Lustin near Namur, enables us to understand the primitive method employed for the manufacture of iron. The furnace consisted of a single excavation in the ground, oval in form and rounded at the bottom; it was about 12 feet long by 9 feet wide and 3 feet deep, and was formed in a bed of clay; a channel pierced through the clay allowed air to enter the bottom of the furnace. In this hollow was found the metal, which contained 93·48 per cent. of iron, 0·37 of carbon, 4·94 of fusible materials, and 1·21 of sulphur and phosphorus.

It is probable that the Romans communicated to the ancient Belgians the use of the bellows, which had long been known to them; and that other improvements were made during their rule in the art of treating iron ores. The invasion of the German tribes probably stopped the impulse given by the Romans to the

manufacture of iron. In the 8th century, under Charlemagne, appeared the furnace called the Fourneau à Masse or Stückofen, which was higher than the old furnaces, and thus allowed a greater concentration of heat. Between the 8th and the 12th century the iron trade developed considerably, and the metallurgist Karsten cites the Low Countries as the district where the manufacture of iron at that period had reached its highest perfection. From thence to the fifteenth century the progress realised was small. In 1468, moreover, the iron works of the Liége district were almost entirely destroyed by the troops of the Duke of Burgundy.

It should be remarked that up to this time malleable iron was almost the only product; but Karsten, who has been cited above, observes that the first apparatus for producing cast iron was established in the Low Countries, from whence the art extended into Sweden and England. The oldest blast-furnace appears to have been constructed near Namur, in 1340. It is, at any rate, certain that before 1400 the foundry-pig blast-furnaces of Les Vennes and of Grivegnée, near Liége, were well known. During the succeeding three centuries the number of blast furnaces grew so rapidly that in 1700 an edict of the Prince Bishop of Liége forbade the erection of any new furnaces for the next twenty-five years.

The use of coke as fuel for blast-furnaces was introduced from England at a relatively recent period. In 1769 an attempt to smelt iron ores by means of coke was made at Juslenville, near Spa, but without success. On the other hand, wood becoming scarce, raw coal had been used for the finishing of malleable iron as early as 1627; but its employment in the process of transforming cast iron into malleable iron was also of foreign importation. This process became common in England whilst it was still unknown in Belgium. It was in 1784 that Cort and Partnell invented in England the puddling furnace and grooved rolls. Those improvements were tried in Belgium; but the French Revolution shortly afterwards put an end to all progress in industrial arts, and the works of the Liége district were in great measure reduced to a condition so deplorable that it was necessary to close them. There was however no long

intermission of activity. In 1800 circular blast-furnaces were found to be replacing the octagonal furnace hitherto in use. Their height was at the same time raised from 15 up to 25 feet. In 1803 the casting of cannon was commenced at Liége, and soon became the largest industry of the province. The idea however was still general that the coal of Liége was not fit for making coke; and it was not until 1823 that an Englishman whose name has become celebrated —John Cockerill—erected at Seraing the first blast-furnace using coke as its fuel. This furnace remained unique of its kind until 1830: it was the origin of the works of the Cockerill Company, now one of the most important on the Continent.

About the same time—in 1821—Michael Orban erected at Grivegnée the first puddling furnace and the first rolling mill on the English pattern. After 1830 the iron trade of Liége made a sudden start, under the double influence of the introduction of railways and the inauguration of large financial companies. In 1839, and afterwards in 1848, serious crises occurred in the trade; but these reverses were succeeded on both occasions by new advances in prosperity.

Hitherto the only ores treated in Belgium had been those from the district of the Ourthe and that between the Sambre and the Meuse. These ores are now almost exhausted down to the level from which water could be pumped to give a profit, and the iron trade of Belgium could not have continued had not new raw material been brought into use. There exists in the Devonian formation an important bed of oligiste or specular ore, of an oolitic character; but for a long time this mineral was considered impossible to reduce. In 1853 however, the blast-furnaces of Ougrée produced a revolution in the Belgian iron trade by succeeding in the utilisation of these ores, and the trade then entered upon a new series of prosperous years.

We may now proceed to the improvements introduced into blast-furnace working. In 1803 the bellows, which had been in use from the earliest times, began to be replaced by blowing engines with metallic pistons; and in 1837 the Cockerill works took the initiative in introducing the hot blast. It was the same works

which introduced into Belgium the making of Bessemer steel. The first converters were erected in 1863.

It is probable that the discovery of the cementation process for the making of steel had its origin in Liége. At the commencement of the seventeenth century, in 1613, a permission to convert iron into steel is found to have been officially accorded to two armourers of Maestricht, a town which then belonged to the province of Liége. Karsten is therefore right in saying, "England, which has now become the school of iron metallurgy, owes to the Continent" (in fact, as we have seen, to the district of Liége) "two great discoveries, viz., that of the blast-furnace and that of cemented steel."

Our notice of the iron trade may be concluded by some details as to its position at the present time. The discovery of the means of reducing the specular iron ores, at the time when the old ores were exhausted, saved the district from ruin. At this moment however the former ores in their turn are nearly exhausted, and the blast-furnaces are almost exclusively supplied, as far as pig iron for puddling is concerned from ores raised in the Grand Duchy of Luxembourg, and as far as steel pig is concerned from ores raised in Spain. Thus, during the year 1882 the blast-furnaces consumed 394,405 tonnes of foreign ores, of which 182,842 tonnes came from Luxembourg and 152,023 tonnes from Spain and Algeria. On the other hand only 82,612 tonnes were indigenous ores.

As a set-off to this disadvantage, the Belgian works are placed in the centre of a district producing coke, which is cheap and of good quality. They are in a country where prices are in general favourable, where labour is abundant, and where workmen are skilful. The ores of Luxembourg are relatively poor in iron, and contain a good deal of phosphorus; but they fuse with great rapidity, inasmuch as they frequently contain a flux within themselves. They have gradually modified the nature of the Belgian trade. A restricted make, of superior quality, has given place to a largely increased make, but no longer of so high a character. The tendency at this moment however is to place the blast-furnaces in the localities where ore is raised, and the works for finishing the iron at the centres of

the production of the fuel. It is found more economical to carry over the same distance one ton of coke and one ton of pig than to carry three tons of ore and flux. This has produced a displacement of the pig-iron industry, which has been transferred in part to the southern part of the Luxembourg province, in the neighbourhood of the mines. On the whole the Belgian iron trade has thus received a fresh advance, in place of declining, as a consequence of the exhaustion of its native ores.

In spite of all the disadvantages which weigh on the country, the care given to every detail, and the application of strict economy even in the smallest points, have preserved to Belgium her place in the metallurgic world, and enabled her to contend successfully against the most powerful competitors.

A few figures will be enough to show the progress which has taken place.

It is known that the low hearths formerly in use produced in 1546 about 300 kilogrammes of iron (6 cwt.) in 24 hours. At the end of the 16th century the blast-furnace then in use produced about 3 tons per day. At the end of the 18th century the production remained almost the same; a furnace at Chimay produced about 720 tons per annum. For any very great advance upon this we must go forward to the coke furnace erected at Seraing by John Cockerill in 1823. This furnace produced about 10 tons in the 24 hours. About 1840, furnaces of a new type, erected about the same time in the Cockerill works and in those of Esperance and of Grivegnée, regularly produced 14 tons of foundry pig or 20 tons of refinery pig per day. In 1848, 24 tons was considered a good average make per day; and in 1860 the Grivegnée furnaces, which gave the best results in production, did not run more than 9,000 tons of pig per annum, or about 25 tons per day. The make has now very largely increased. The Seraing furnaces produce from 65 to 68 tons of Bessemer pig per day; whilst at Ougrée two furnaces produced altogether in 1882 more than 41,000 tons. In making pig iron for ordinary puddling, a make of more than 90 tons per day has been attained. The blast-furnaces at Esch, on the Alzette, in the Grand Duchy of Luxembourg, produce as much as 110 tons per day.

As to wrought iron it is difficult to give exact figures. The skill of the workman is a main element in the quantity produced; and the improvements effected by the substitution of coal for wood have had a large influence on the price, without greatly changing the capacity of production. The attempts to puddle by machinery have had little success, and progress has been realised chiefly in the economy of fuel by means of gas furnaces, especially the Bicheroux furnace.* Whereas formerly about one ton of coal was required for every ton of puddled bar produced, 505 kilogrammes (11 cwt.) are now sufficient.

As regards steel, we will only consider the steel produced by the converter process. The first Bessemer converters, erected at Seraing in 1863, gave 10 to 12 tons of steel per day. At present each pair of convertors may be reckoned on to give from 150 to 160 tons in the 24 hours, and on the new American system 340 and even 360 tons have been obtained.

As a matter of statistics, the annual production of the works in the province of Liége was estimated in 1829 at 7,078 tonnes of pig iron, 660 tonnes of castings, 5,011 tonnes of wrought iron, and 4,778 tonnes of iron manufactured for various purposes. The manufacturing works employed 711 workmen. In 1850 the make of pig iron had risen to 65,393 tonnes; that of castings to 7,688 tonnes; that of wrought iron to 23,252 tonnes; and lastly, that of manufactured iron to 7,093 tonnes. In 1882 we find that the province of Liége contained 13 blast-furnaces actually in blast, and employing 1,215 workmen. The make of pig iron was 238,968 tonnes. The production of wrought iron and of manufactured iron was 126,461 tonnes, and occupied 5,180 workmen. Lastly, the steel works contained nine converters, produced 171,937 tonnes, and occupied 2747 workmen.

The average wages of the workmen employed at the blast-furnace is 3 francs per day (2*s.* 6*d.*); those employed at works for making or for working up wrought iron get an average of 3·46 francs per day (2*s.* 10½*d.*); whilst those employed at the steel works, properly so called, earn on an average 3·58 francs per day (3*s.*)

These works on the whole have been actuated by 473 engines of various kinds, giving a total power of 14,688 HP.

* For a description of this furnace, see below, p. 542.

II. The Coal Trade.

In sketching the history of the iron trade we have met at every step with one element indispensable to its progress, namely coal; and the coal trade is of sufficient importance in Belgium to give interest to some details as to its history.

The discovery of coal in Belgium dates from the middle of the twelfth century. A legend states that an angel appeared to a blacksmith of Plainevaux (a village situated in the neighbourhood of Liége, near Seraing), who was complaining that he could not earn his livelihood on account of the excessive dearness of wood, and advised him to go to the heights of Publémont, near Liége, on which stood the Monastery of S. Laurent; there he would find a black earth, easy to kindle and fit to use instead of wood. The blacksmith went to the place indicated, and there found coal, of which he began to make use. His name was Hullos or Houllos, and it is from him that coal took its French name of "houille."

It should be added that the author who transmits this legend, Father Bouille, himself suggests that the angel in question (Angelus) might have been an Englishman (Anglus), and that in the old Latin manuscripts the one word might have been mistaken for the other. However this may be, it is certain that the working of coal in the province of Liége began at a very distant period. As is shown by the geological section of the coal basin of the Meuse, the beds crop out at several points, and it is natural that the use of this rock, so different in appearance from others, and endowed with properties so remarkable, should have been known at a very early stage in the history of the country.

Advancing to the present day, we find that the chief difficulties which beset the mining of coal have all to be encountered in this locality. The workings have attained a very great depth, and would be overpowered by water and by fire-damp were it not for the improved engines which now exist.

We will sketch the mode in which these difficulties have been overcome. The first workings of coal were undoubtedly in the open air; subsequently headings were driven along the beds from the

hill-side. As these beds descended below the surface, it was soon necessary to follow them by means of sloping galleries. Before long it became difficult to prevent the rain from filling these excavations, and at the same time the lifting of the coal to the surface became more and more troublesome. It was necessary to find means for overcoming these difficulties, and it is probable that chance led to their discovery. The same bed had been attacked at two outcrops, near the summit and near the bottom of the hills; the two workings accidentally met each other, and it was found that the waters from the surface ran out at the bottom. Such is probably the origin of the "Areines," or adits for drainage. The earliest of these at Liége dates from the thirteenth century; there is one which at this moment comes to the surface near the church of St. Antoine, and which is mentioned in the records of 1243; and the fountain in the market place is still fed by water coming from old Areines.

Working by shafts goes back to the end of the 12th century; but they were only used in order to descend along beds which were inclined at a very steep angle; they were, in fact, sloping headings rather than actual shafts. The invention of gunpowder furnished the means of attacking hard stone, and thus sinking vertical shafts, or driving headings across the rocks which separate the several beds of coal.

In the 18th century the average depth of the mines was 650 feet. At the same period, in order to prevent too great an inflow of water, tubbing began to be employed, first in wood and afterwards in cast-iron, when at a later period this system was introduced from England. Finally, about 1850, M. Trasenster conceived the idea of replacing brickwork by cut stone in this description of work.

The process of sinking by means of compressed air, in order to pass through soft and water-bearing strata, was employed for the first time at Liége by the Sclessin Company, when sinking the Perron shaft now belonging to the Company of Val Benoît and Grand Bac. This process was again taken in hand and much improved, in 1857, by the Cockerill Company, in order to sink the Marie shaft; and was afterwards used for sinking the new shafts of the Horloz Colliery at Tilleur.

Coal was originally lifted from the pit on the backs of men; then for a long period in panniers; afterwards in tubs hung from a rope or chain, which was wound round capstans worked first by men and afterwards by horses. Steam winding-engines were imported from beyond the Channel: the first was installed in 1811 by M. Orban at the Plomterie Colliery. For a long time the Belgians were content to follow the footsteps of the English in adopting geared engines, with the subsequent improvement of coupling the engines directly to two cranks at right angles on the shaft of the winding drum. This system was applied for the first time in Belgium by the firm of Charles Marcellis at the Bois D'Avroy Collieries, in 1847. The same firm erected in 1860 for the La Haye Collieries the first expansive winding-engine. This had a fixed grade of expansion on the Meyer system, and solved the problem of disconnecting the expansion gear at the beginning and end of each run, with a simplicity which has never been attained subsequently. The gear was disconnected by simply bringing the link-block of the reversing gear to the middle of the link.

Much attention has been given in Belgium to the means of varying the expansion during the run of the winding-engine, so as to proportion the power to the resistance at each instant. Several solutions have been proposed, of which that of MM. Brialmont and Kraft is one of the best; but it is difficult to obtain from the engine-man the attention necessary to operate the lever which regulates the expansion. The engine-men have been accustomed to proportion the power to the resistance by throttling the steam with the throttle-valve. The experiments of M. Hallauer have shown that this method is not so barbarous as it appears, and does not waste fuel, provided that the variation is not too great. In consequence the use of variable expansion has lost much of its interest, except where the depth is very great. In this case its advantages return, but it must be rendered independent of the hand of the driver. The last progress made in this direction was by M. Beer in 1871; he made the expansion automatic by connecting it with the movement of the governor.*

* See also Description of the Mariemont and Bascoup collieries, below, p. 570.

At the Marie Collard pit at Seraing can be seen a fine example of the improvements recently introduced in the winding process. These comprise a round rope of steel weighing not more than 5·7 kilogrammes per mètre run (11½ lbs. per yard) or 6670 lbs. for a depth of 580 yards. It is wound upon a drum worked by an engine with variable expansion: the cages are also made of steel.

The descent of the colliers into the pits was originally carried on by nothing but ladders placed in one compartment of the shaft. This system offered one advantage only—that of safety. It was thus that from 1840 to 1844, during which fifteen accidents took place in the Belgian mines, five miners only were injured on the ladders; in 1849 only two men were wounded, and in 1851 there were merely two men bruised. By degrees however, with the increase of depth, this system became too slow and fatiguing; the miners were then allowed to descend by the tubs used for drawing water and coal, and subsequently in the cages, especially when the latter had been furnished with safety appliances. These last were first used in Belgium in 1846, and have since been improved, without arriving however at any absolute security. Man-engines were for a time used to a certain extent, but can nowhere be found in the district now.

As to lighting, the original method consisted simply of a candle fixed to the miner's hat by a lump of clay. A particular workman called the "Penitent" was charged with the duty of going every morning with a candle at the end of a long rod to kindle the fire-damp in recesses where it might have accumulated. In spite of the terrible and numerous accidents which had demonstrated the dangers due to fire-damp, still when, in 1817, M. Orban introduced the Davy Safety-Lamp, its adoption was for a long time opposed by the force of custom; and it required two successive explosions in 1822 and 1823—in the latter of which thirty workmen were killed, and the survivors saved by an overman provided with a safety-lamp—to prove to the Liége miners the advantages of the new invention.

The Davy lamp is, however, far from offering absolute security, especially in rapid currents of air; and in 1840 an engineer of Liége, the late M. Mueseler, improved it by augmenting its lighting power,

and especially by giving it the important quality of self-extinguishment as soon as the surrounding atmosphere is sufficiently mixed with fire-damp to be explosive. Numerous Commissions have experimented on different systems of lamps in use in fiery mines, notably the Belgian Commission appointed in 1868, the French Fire-Damp Commission, and different private Committees appointed by engineering societies in England and France. They have unanimously reported that in rapid currents the Mueseler lamp offers a better resistance to gas than any other. The Davy lamp causes an explosion in a current of 1½ to 2 mètres per second (5 to 6 ft.), whilst the Mueseler lamp resists currents from 4 to 5 mètres per second (13 to 16 ft.) and even more. At the time of the recent disaster at L'Agrappe, which cost the lives of more than a hundred miners, a sudden outburst of gas issued from the shaft, and burned for several hours like an enormous gas-burner. It only caught fire at the surface, and no explosion took place inside the mine, the 220 Mueseler lamps which were employed there having all of them become extinguished.

These instantaneous outbursts of gas appear to be an unfortunate privilege peculiar to the Belgian mines. They have taken place on several occasions and in large volume, without any previous intimation that they were about to occur. Enormous quantities of gas suddenly escape from the beds of coal, oversetting everything in their passage, and accumulating in the workings immense quantities of coal dust. Science itself has hitherto been powerless to deal with these frightful accidents.

The Mueseler lamp extended rapidly in use after 1844. On the 1st January 1860, 14,597 lamps of this type were already in use in the province of Liége. They are now employed exclusively throughout the fiery mines of Belgium, where their price is from 5 to 6 francs apiece.

The existence of fire-damp is mentioned for the first time in the 15th century by the historian of Liége, Bartholomew Fisen. It appears it was first found in the mines on the shores of the Meuse; and it is said to have appeared in a form resembling spiders' webs, which it was sought to disperse by agitating the air with sticks and

with cloths. Efforts were soon made to get rid of the gas by renewing the air, and ventilating shafts were employed from 1696. Even when the mines were still of small depth, these were found to be necessary. A furnace was lighted at the bottom of the shaft, to augment the draught of air. The first ventilating machines were pressure pumps worked by windmills. Large bellows, similar to those of the blacksmith, were also employed. Steam came in subsequently to transform completely the principles of ventilation, by substituting the process of exhaustion for that of pressure.

The first steam ventilators were piston pumps, which still exist at the Esperance shaft, and at Seraing, where they were installed in 1835. A similar machine with air-vessels was installed at Mariehaye in 1842, and has been often imitated since; amongst other places in the construction of the Mont Cenis and St. Gothard tunnels. In 1845 M. Fabry invented his rotary pumps, which still remain in favour to a certain extent. A remarkable specimen can be seen at the Marihaye colliery, one of the most fiery mines in the Liége basin. Shortly afterwards M. Lemielle invented a ventilator founded on the same principle as the last named, viz., the formation of a vacuum within a space varying in size, into which the air from the mine passes, and from which it is expelled outwards by means of an impressed rotary motion. A fan on this system, and of colossal dimensions, can be seen at the Horloz Colliery. Lastly, M. Guibal invented his centrifugal fan, provided with an exterior casing and a chimney. This last system is at present mainly in fashion, not only in Belgium but in all mining districts. It is not rare to see Guibal fans having a diameter of 12 mètres (40 ft.) running at 80 revolutions per minute, and discharging 50 cubic mètres of air per minute (1,760 c. ft.) with a vacuum of 215 millimètres head of water ($8\frac{1}{2}$ inches). In England they have even been constructed of a diameter of 46 feet. This system has numerous good qualities, which give it the preference over others in all cases where the volume of air to be drawn, and especially the vacuum to be produced, does not necessitate dimensions which are altogether out of the question.

Ventilators present great advantages over the furnaces still employed in many places in England. Independently of the

permanent danger which the latter offer in fiery mines, they have the further inconvenience of consuming a vast amount of coal, and not having the same efficiency as fans for great depths. There is still to be mentioned the Harzé ventilator, in which the Guibal chimney has been replaced by a diffuser on the Rittinger system. These ventilators can be seen at the Lonette and other collieries. At the Marie shaft in the Seraing Works a turbine ventilator was put up in 1878. This ventilator has a diffuser and guide-blades, and was constructed according to the theory of turbines from the designs of M. Kraft, chief engineer to the Society Cockerill. Lastly, in several collieries within the basin, the steam-jet ventilators of Körting Bros. have been erected for cases of emergency. These ventilators are based on the same principle as the Giffard injector.

We have still to record the progress made in the district as regards the drainage of mines. The first methods of drainage, as we have said, were the areines or adits; but when coal had to be sought below the level at which adits could be driven, recourse was had to the raising of water in tubs or barrels. For this purpose a sump or reservoir was excavated below the level to which the mine was to be worked; into this sump all the water of the mine was run during the day, and it was emptied during the night. Soon however the amount of water became so great that special shafts were obliged to be reserved for its extraction. From 1630 it became necessary to employ pumps, which were worked by water or wind-power. The principle of a main pump-rod working several bucket and plunger lifts was already known; and it may be remembered that it was a citizen of Liége, Renkin Sualem, who constructed the famous hydraulic engine at Marly, near Marseilles, in the reign of Louis XIV. Here again we see steam introducing a complete transformation in the systems employed. In 1767 there were already four steam pumping-engines in the Liége basin; these were atmospheric engines on the Newcomen system. After this came the engines of Watt, which for a long time were employed almost exclusively. In 1827 the Society Cockerill erected at the Colliery des Artistes at Flémalle Grande the first large direct-acting rotary engine; but this system

was abandoned, and fashion returned to the beam engines of the Cornish type. However, from 1837 the simplicity of the direct-acting and non-expansive engine, and its economy in first cost, gave it the preference in Belgium over other systems. The first direct-acting engine was erected at Ans, in the Bonne Fortune Colliery. Several collieries followed this example, and the firm of Ch. Marcellis, now the Compagnie des Ateliers de la Meuse, introduced great improvements into engines of this kind,—in particular the Letoret condenser, and modifications in the tappet gear. Expansion was also applied to these engines, but was found difficult in consequence of the enormous masses which were set in motion. To diminish this inconvenience, the firm of Ch. Marcellis applied the Woolf or compound system for the first time, in 1859, to the engines which they erected for the Moresnet mines of the Vieille Montagne Company.

The rotary engine of 1827 was however destined to regain favour, and in 1863 M. Colson erected a new rotary engine at the Many pit at Marihaye. The Cockerill Company also erected a large rotary engine on the Woolf system at the Bleyberg mines; and in 1878 Rittinger pumps were attached to a rotary engine erected at the Gosson Collieries. Numerous engines of this class may now be seen in the Liége basin.

At the same time direct-acting engines present certain advantages, which will yet give them the preference in cases where economy in first cost and facility of maintenance are of more importance than economy in fuel. In fact, in direct-acting engines the consumption of fuel does not exceed 3 kilogrammes per effective horse-power in water raised per hour (6·6 lbs.), whilst with rotary engines the amount falls to 2 kilogrammes (4·4 lbs.) and even 1½ (3·3 lbs.).

Underground pumping engines are little used in Belgium; two however have been recently erected in the basin, namely at the St. Marguerite and at the Horloz Collieries.

A few figures will give an idea of the progress attained in the coal trade of the province.

In 1765 there were only 97 coal mines in the Liége district; in 1855 the province of Liége alone counted 115 coal mines, and the

production was 1,720,053 tonnes. Lastly, in 1882 there were 56 coal mines at work; they employed 23,694 hands, whose average yearly wage was 975 francs, and yielded a yearly total of 3,993,482 tonnes. This total is made up as follows:—

	Tonnes.
Non-bituminous coal	408,096
Partially bituminous coal	1,260,811
Bituminous coal	2,324,575
Total	3,993,482

The steam winding engines are 105 in number, and have a total power of 9,450 HP. Pumping is carried on by 64 engines, with a total of 12,280 HP. These engines, in 1882, raised from a mean depth of 263·5 mètres (865 ft.) a quantity of water equal to 20,698,055 cubic mètres (about 730,964,000 c. ft., or 45,539 millions of lbs.). The cost per cubic mètre, lifted 100 mètres, was in many cases below 2 centimes (0·277*d.* per million ft.-lbs.). Lastly, there were 82 ventilating machines consuming 1,680 HP.

In 1882, 834,212 tonnes of coal were converted into coke, and produced from 1,602 ovens 615,281 tonnes, giving a mean yield of 70 per cent. This high yield is due to the employment of improved ovens. Those chiefly in use at present are the Coppée and the Appolt ovens, the latter being especially suitable to the less rich coals worked in the Seraing basin. The so-called Beehive ovens have entirely disappeared from the district, on account of their restricted production and of the nature of the coal, which requires to be attacked by a powerful and sudden heat.

To conclude this description, already too long, and yet very incomplete, it only remains to ask indulgence for the numerous imperfections which it presents, and to thank those whose previous labours have facilitated the task undertaken by the writer. Amongst these he would wish to cite the papers of M. Franquoy, Director of the La Haye Collieries, which deal with the iron trade of the Liége basin, and also those of M. Renier Malherbe, Ingénieur au Corps des Mines, and Superintendent of Public Works for the town of Liége, which deal with the coal trade: both of these have been published

by the Société d'Émulation at Liége. He would also refer to the description by M. Julien Deby, published on the occasion of the visit of the Iron and Steel Institute to Liége in 1873; to the Reports of M. Van Scherpenzeel Thim, Chief Engineer of the Liége province, on the Mineral and Metallurgical Industries of the province during the year 1882; and lastly, to the Reports of M. A. Habets, Professor of Mining at the University, upon the Exhibitions at Vienna in 1873 and at Paris in 1878.

On casting his eyes back along the line of history which we have been tracing, a Belgian may venture to congratulate himself on a brilliant past; to rejoice at the importance of the position assigned to his country in the present; and to hope for a future of prosperity to be shared with his own by all industrial nations, and more than any other, by the chief among them all—England.

ON THE MANUFACTURE OF ZINC IN BELGIUM.

BY M. ST. PAUL DE SINÇAY, OF CHÊNÉE.

At the epoch of the Roman invasion the Belgians were already distinguished for their skill in the working of metals. Under the reign of Charlemagne they understood their artistic treatment; and by the tenth century they had acquired great skill in the casting and chasing of goldsmith's work, as is shown by the numerous and remarkable specimens preserved to this day. There is therefore nothing astonishing in their having been the first nation of Western Europe to understand and practise the manufacture of Zinc.

The continual communication which, from a very remote epoch, they kept up with the east by way of Germany, introduced into their country a new metal of a fine yellow colour, and having the qualities of copper. This metal the Greeks distinguished by the name of Orichalcum; it had been produced from a remote period in Asia Minor, and in the Isles of the Archipelago. The Belgians soon learned that it was made by alloying copper with a mysterious substance contained in calamine rock. This rock was probably known throughout a large part of Belgium, because both in the strata of the Devonian formation and in those of the carboniferous era it formed numerous superficial deposits, near the banks of the Meuse between Givet and Liége. Again, in a corner of the Duchy of Limbourg, not far from the Liége district and from the frontiers of Germany, there existed a bed of this mineral having an exceptional richness and extent. This great bed was subsequently named, from the territory containing it, the Moresnet bed. It is generally admitted that here was the seat of the first working of calamine (carbonate of zinc); it is at least certain that at a very distant epoch this mineral was mined there, but the actual date when the working was begun has not hitherto been exactly determined. Ancient documents

relate that calamine was raised in the neighbourhood of Moresnet at the beginning of the fifteenth century. Under the date of July 5th, 1435, mention is made of the concession of a zinc mine accorded by the Duke of Limbourg. In a record of 1439, a notice occurs of the calamine mountain "which the men of Aix were accustomed to work." This working, at that time abandoned, must have dated from a very distant period. From this circumstance the calamine bed there worked received afterwards the name of Vieille Montagne, or Altenberg. In 1454 the working of this mine was recommenced, according to a concession made by Philippe le Bon to the Sieur Arnold Van Zevel.

This mine, which must have been so long in existence, was at that time the most esteemed for the abundance and the quality of its products. These were calcined, or burnt, as it was then called, on the spot; for which purpose wood-charcoal was employed, made in the forest of Hertogenwald. Thus prepared the ores were sold, and transported to different localities where copper was beaten. Such works existed at Aix, at Stolberg, and at Cornelius-Munster; but the brassworks of Dinant, Bouvignes, Oignies, and other localities near Namur, bought the greater part of the make, and transported it to their works on carts as far as Visé, from whence they made use of the two great rivers, the Meuse and the Sambre.

It is known that they prepared the yellow metal by mixing in crucibles red copper from the Tyrol and calamine, after an addition of charcoal; they then transformed the brass, whether cast or hammered, into articles of all kinds, which were known under the name of Dinanderies. Specimens of these are still existing, and bear testimony to the remarkable skill of their artists.

Thus there is reason to believe that the working of calamine in Belgium began at about the same time as the making of brass, and was already practised in the 12th century.

For a long time, under the Dukes of Limbourg and of Burgundy, and likewise under the Spanish princes, the mines of the Moresnet district were let to mining companies under temporary concessions not extending beyond twelve years. At certain periods the Government, from motives of policy or otherwise, preferred their own management

to the system of leases, and worked mines by their own officers and to their own profit. This was especially the case under the Archdukes Albert and Isabelle, and later in the time of Philippe IV. of Spain. The Austrian Government, like the Spanish sovereigns, followed sometimes the practice of leasing and sometimes of working on their own account.

The raising of calamine was considered from the first as an important branch of national industry, as is best proved by the numerous regulations to which it was subjected. In order the better to ensure its development, the public authorities went so far as to interdict the importation of foreign calamine. After the annexation of the Belgian provinces by France, in 1795, the Government of the Republic itself worked the Vieille-Montagne mine for the profit of the nation; but this attempt at Government working soon produced a great diminution in the returns. Hence it was speedily renounced, and in 1806 the mine was let to Daniel Dony, of Liége.

Up to this period Belgian calamine had only served for the making of brass; but for some time the question had been agitated of extracting from it the metal which it contained, and which laboratory experiments performed at Liége about 1769 (especially by Prof. Villette on the instructions of Margraff) had shown to be of excellent quality. The object was to replace by a national product the zinc made in the foundries of Germany, and also the "tutenag," an impure zinc brought by the ships of England and Holland from the furthest east.

The progress which chemistry had made, thanks to the labours of Lavoisier and other scientific men, had spread widely the taste for research and experiment. From different quarters attempts were made to discover a new method of working zinc, appropriate to the nature of the Belgian ores; and under this impulse the Government imposed on their lessee, Dony, an obligation to make "such experiments as might be judged useful, in order, by the aid of suitable furnaces, to reduce the calamine to a metallic state." Dony accepted these conditions, and set resolutely to work. The task was a difficult one. It required long effort, great expense, and numerous attempts; but the original and persevering genius of Dony overcame all

difficulties. On the 7th December, 1809, he demanded a patent for 15 years, "for the construction of a furnace suitable to extract zinc from calamine, and for the processes employed in this operation." This patent was accorded to him by Imperial decree on the 19th January, 1810. The Liége method of reducing zinc ores was now discovered, and Dony had given his country a new industry which was destined to have a vast development.

The small establishment which he had founded at Liége in the Faubourg St. Léonard, in order to carry out his researches, became the earliest zinc works of Belgium. The second furnace was started on the 28th January, 1810. The position of this foundry was excellently chosen, placed between two populous suburbs and in the neighbourhood of the collieries. It was also able to make use of two main roads and of the Meuse, to receive its raw materials and to deliver its products. This establishment played an important part in the history of Liége. After numerous vicissitudes it was closed in 1880. A square and several streets have been built on its site, the names of which will still preserve the recollection of the principal authors of the zinc industry and of the main site of calamine working in the district.

The discovery of Dony had cost the inventor considerable sums required for his experiments. He was recompensed by the protection of the authorities and by the praises of scientific men; but this was not sufficient to restore his broken fortunes. Metallic zinc was at that time applied to very few purposes. Dony hoped to find a market for his metal with the brass-founders; but these, influenced by routine, preferred to treat their copper by means of calamine, as their fathers had done before them. This failure imposed upon Dony further efforts, and a second task still more arduous than the first. After having discovered the method of producing zinc on an industrial scale, it was now necessary to find applications for it, and to promote its use. In one word, the newly obtained metal had to find its place in the ranks of ordinary and necessary materials.

Indefatigable as ever, Dony set resolutely to work, but the effort was beyond his power. He associated with himself for some time the Sieur Chaulet; but in 1818, completely ruined and worn out by

his labours, he resigned in favour of Dominique Mosselman. The latter gave a strong impulse to the zinc trade, but despite his great powers and rare energy he did not succeed any more than Dony in bringing to completion the work which he had undertaken. In 1837 his sons took up the task, and formed with their father the Société de la Vieille Montagne.

The resources of the new company were considerable. In the first place they possessed the great calamine concession whose name they bore, comprehending the whole Moresnet district. Next, they possessed two foundries in actual work—that of St. Léonard, which was now considerably enlarged, and another recently erected near the mine on neutral territory. A third zinc works then in course of construction at Angleur, on the left bank of the Ourthe, also belonged to them.

In 1837 the two first of these foundries produced together 1,833 tonnes of zinc; the next year the Angleur works contributed to the production, which rose to 2,540 tonnes. Thanks to the creation of new markets, the make of zinc then received a large development: new furnaces were built, and the production of the three works of Vieille-Montagne advanced rapidly from year to year; as is shown by the following Table, which gives the production of the zinc works at Moresnet, Angleur, and St. Léonard from 1839 to 1852.

Year.	Tonnes of Zinc.	Year.	Tonnes of Zinc.
1839 . . .	3,336	1846 . . .	6,720
1840 . . .	3,631	1847 . . .	6,156
1841 . . .	3,891	1848 . . .	6,060
1842 . . .	4,508	1849 . . .	7,844
1843 . . .	5,105	1850 . . .	9,180
1844 . . .	5,665	1851 . . .	9,755
1845 . . .	5,941	1852 . . .	10,372

By the annexation of several competing works the Vieille-Montagne Company has seen its production increase from year to year, until in 1882 it reached a total of 49,000 tonnes of raw zinc, 36,000 tonnes of which were made in Belgium.

During the same period several new establishments for zinc working were founded in Belgium. Among the first of these should

be mentioned the Nouvelle-Montagne Company, founded in October, 1845. The two works of this company, situated one at Prayon, near the Vesdre, and the other at Engis on the Meuse, produced in 1846 about 1,357 tonnes of raw zinc. They were supplied with calamine from the royalties of the Nouvelle-Montagne, which were situated between Verviers and Stembert, and from the beds at La Mallieue and Les Fagnes, near Engis. The first of these mines was leased on the 7th May, 1829, and the second on the 17th May, 1830. The working of calamine at La Mallieue has existed for a long time; the brassmakers of the Namur district took their supplies from thence at the beginning of the seventeenth century. It was in exploring along a bed of carboniferous limestone, with the object of working alum shale, that calamine had been met with; it was associated with ores of lead. The annual yield of these Nouvelle-Montagne zinc works rose gradually; in 1865 it attained 3,749 tonnes; it then sank below 3,000 tonnes, but rose rapidly from 1874, and has now reached the figure of 6,650 tonnes.

In 1882 the Prayon works were separated from the Nouvelle-Montagne, and re-started by a new company, bearing the name of Société Anonyme Métallurgique de Prayon.

In 1841 metallurgical works were erected in the Commune of Antheit, near Huy, for treating the ores of zinc and lead derived from the Corphalie mines, which had been conceded in June 1829. A Company was formed in July 1849, under the name of the Société de la Corphalie, to continue the working of these mines. The company also possessed the right of exploration in the calamine beds of Sielles and of Landenne-sur-Meuse, especially at the place called Hayes-Monets; this concession was obtained in February 1848. The production of raw zinc at the Corphalie works was below 1,000 tonnes up to 1847; it then rose from year to year, and in 1869 reached 6,112 tonnes. After a period of reverses, it took a new departure in recent years, and is now above 8,000 tonnes. In 1863 the Corphalie Company, being amalgamated with a zinc mining Company situated in Croatia, changed its name to that of the Société Métallurgique Austro-Belge.

At the same date the firm of MM. de Laminne of Liége erected at

Ampsin a zinc foundry on the banks of the Meuse, and also works for calcining zinc ores at Bende, on the plateau which overlooks the Meuse on the side of La Hesbaye. The foundry turned out 1,181 tonnes of metal in 1856; but owing to the development of its capacity it is now able to supply more than 6,000 tonnes per annum.

The Grande-Montagne Company was formed in 1846 to work the zinc-bearing beds of Flône, and built in this district a foundry which was started in the succeeding year, and which after some vicissitudes was taken over by the Vieille-Montagne Company in 1853. It was then supplied by ores from different mines, like the other foundries of the same Company. In 1854 its production was not more than 1,510 tonnes: since that date it has quadrupled itself.

The Société Anonyme des Houillères et Fonderies de Zinc de Valentin Cocq was founded like the last in 1846, and was merged at the same time in that of the Vieille-Montagne. Its works are situated at Hollogne-aux-Pierres, and at that time already produced 2,391 tonnes per annum. The production has since developed rapidly, and now reaches nearly 18,000 tonnes. The Valentin Cocq foundry is the largest zinc works in Europe.

The "Société Anonyme de zinc, blanc de zinc, et charbonnage, de Colladios" was founded in 1853, and built at Mons, near the Valentin Cocq foundry, zinc works, the make of which was always below 500 tonnes. This foundry was bought by the Vieille-Montagne Company in 1865, and joined to the great works of Valentin Cocq.

The Société de Bleyberg-ès-Montzen added in 1855 a zinc foundry to its lead works, in order to treat the calamine of Schimper, as well as blende extracted from its great vein of lead, and found associated with galena. This foundry, whose annual make has for a long time been only about 1,000 tonnes, has recently received great enlargement, and its capacity is now about 5,000 tonnes.

The zinc work at Ougrée, now belonging to Messrs. Eschger, Ghesquière et Cie., dates from 1859. Its annual make, which was for several years small, is now above 4,000 tonnes of raw zinc.

The most recent works in Belgium are those of Messrs. Dumont Frères of Liége, erected in 1875 at Sclaigneaux, near their lead works.

It has developed rapidly, and its annual capacity is already as much as 6,000 tonnes of zinc.

On the whole it appears that Belgium now possesses eleven works for reducing zinc ores, and all in a state of high activity. Their capacity has developed gradually, and in 1882 they were able to turn out 71,565 tonnes of raw zinc. The following Table gives the distribution of this total make:—

Works.	Tonnes.
Vieille Montagne	35,940
Austro-Belge	8,099
De Laminne	6,255
G. Dumont et Frères	5,500
Nouvelle Montagne	5,480
Bleyberg	4,647
Ougrée	4,144
Prayon	1,500
	71,565

This total figure represents about one-third of the whole production of Europe, but will probably be considerably surpassed in 1883. In so active a state of trade it is not to be wondered at that the annual amount of ore consumed is considerable; it is, in fact about 200,000 tonnes, only a part of which is furnished by the mines of the country.

Belgium, as we have said, is rich in zinc-bearing strata; some of them consist of calamine, others of blende, mixed with sulphates of iron and of lead. The greater part of these are under concession, and are worked to a greater or less extent. The principal concessions have already been mentioned; the others would form a long list which it is not worth while to give.

For many years calamine (carbonate of zinc) was the only ore treated in the Belgian zinc works. The preference thus given to it is easily explained by the facility with which it lends itself to metallurgical operations. For a long time it was believed impossible to utilise the blende (sulphide of zinc); but thirty years ago the making of zinc began to be largely extended, and it was necessary to have recourse to new supplies of mineral. Attempts were then made to make use of blende; special workshops were constructed for

desulphurising the new ore, and before long a considerable proportion of this ore was supplied to the foundries. In Belgium the chief works for roasting blende are those of Bleyberg, Engis, Flône, Ampsin, Corphalie, and Sclaigneaux.

It would be difficult to estimate the quantity of zinc ores, carbonates and sulphides together, which have been extracted from the Belgian mines. It must be very great, since from 1837 to 1882 the mine of Moresnet Neutre alone, belonging to the Vieille-Montagne Company, produced 1,295,290 tonnes of calamine. The calamine earths, which are found with the ore-bearing rock, are generally very poor in zinc, but are made richer by washing. The same is the case with the blende, which must be separated from the other sulphides with which it is almost always associated; but on account of this separation the mechanical preparation of blende gives rise to operations which are usually of a very complicated character.

Belgium possesses several large works for the mechanical preparation of zinc, such as those of Moresnet, Welkenraedt, Bleyberg, Engis, Flône, Bende, Corphalie, and Sclaigneaux. These have a high reputation for the excellence of their manufacture. In several of these, appliances which are now known and appreciated throughout the world have had their origin. Except the Moresnet works, which only treat calamine from the neutral territory, all the Belgian foundries receive a part of their supplies of ore from abroad. It was the mines of Spain which first came in to aid in their supply; to these were subsequently joined those of Sardinia, Greece, Algeria, Sweden, France, Germany, and England.

Foreign calamine is generally calcined before being shipped; blende, on the contrary, is usually shipped in its raw state, and has to be submitted in Belgium to the preparatory treatment which its nature requires. Almost all these ores are brought by sea to Antwerp, where several agencies exist to receive them, and forward them to the zinc works, whether by railways, with which all the works are connected, or by canals, or by the Meuse: most of the works being equally accessible by the latter channels.

The Belgian foundries require from abroad nothing more than a supply of ore; for everything else they find in their own country and

neighbourhood all the resources necessary. Situated in more or less close vicinity to numerous collieries, they can choose the bituminous coal best suited to the system of furnace they have adopted. They receive from different sides, both from the basin of the Charleroi and that of Liége, non-bituminous coal and small coal, which they employ for reducing purposes.

It is well known that for the manufacture of zinc, as for many others, the question of refractory materials is of very high importance. The Belgian works obtain from large beds near Ardenne a refractory clay, with which they manufacture articles of an excellent quality, and of long-established reputation.

But the special strength of these works lies in the fact of their possessing a class of workmen, strong, intelligent, experienced, active, well-disciplined, fond of their trade, and deeply penetrated with feelings of duty. Amongst this industrial population, which, without counting labourers, numbers some 7,000 workmen, there are many who have saved enough to buy the houses which they inhabit, and the gardens which, after the rough labours of the shop, they find time to cultivate themselves. The workmen at the Valentin Cocq works, belonging to the Vieille-Montagne Company, are distinguished in this respect, since at least half of them are proprietors. This love of property and care for the future is nothing surprising. For a long time past the Company has done its best to inspire this feeling by creating institutions of thrift, intended to ensure the material, moral, and intellectual good of the working classes.

The first care of the Company was to give all their workmen a share in the wealth which they procured, proportional to their efforts and their success. The arrangements as to wages and allowances were made in this spirit. Subsequently the work was completed by establishing the following institutions, all intended to ameliorate the condition of the workmen, namely:—A Sick Fund, a Provident Fund, a Savings-bank, and a Life Insurance Fund. The two first are workmen's institutions in the full sense of the word; the Sick Fund is formed entirely by a sum deducted from the workmen's wages, and is used to supply their present needs in case of sickness or injury. The Provident Fund, which is supplied by payments from the

Company, is intended to provide for the future need of the workman when age or infirmity renders him incapable of labour. This solicitude for the working-classes on the part of the Vieille-Montagne Company has been imitated under different forms by the other Belgian works; and these measures have received a practical sanction which is worth noting—namely that, so far as the writer knows, this industry has been wholly free from those strikes which have so often brought disaster upon the trades of the miner and the ironworker.

METALLURGY OF ZINC.

The different processes for the reduction of zinc ores are well known. The *per descensum* process has scarcely ever been practised except in England. On the Continent the methods in general use are the Liége method and the Silesian method. Neither of these since its commencement has undergone any essential change, and they may be employed at present side by side with each other.

The Liége furnace is generally higher than its width, and contains six, seven, or even eight horizontal ranges of crucibles. These furnaces occupy little space, and also consume less fuel than the Silesian furnaces. The latter, on the other hand, are cheaper as regards labour and the durability of the distilling apparatus. To complete the essential distinctions between the two, it may be said that the Silesian furnaces are specially adapted for treating poor ores; and this should be so, since they were invented to reduce the calamines, low in proportion of metal, which are worked in Silesia.

Belgium, as might be expected, has remained faithful to the Liége or direct-heating process, inaugurated by Dony. The works of Valentin Cocq and Flône are the only ones which possess furnaces agreeing with the Silesian system in their mode of heating; but being provided as they are with crucibles in three ranges, they share equally the advantages of the Liége method.

Great efforts have been made to perfect the metallurgy of zinc. These have opened the way to progress in many respects. In all the operations required—in the preparation of the refractory materials concerned, in the crushing of the ores, in the composition of the

charges, in the construction of the hearths, in the arrangements and dimensions of the heating chambers—important improvements have been realised: in all, new and improved appliances have come into use, which, for the most part, are due to eminent manufacturers in the district. Above all, changes have been made tending to render more easy and less dangerous the labour of the workmen. Thanks to other improvements, the results of the process have been sensibly improved. It has especially been sought to augment the production of the furnace, to reduce the "écart" or loss of metal during treatment, and lastly to diminish the consumption of fuel. In all these ways notable progress has been realised.

The zinc vapours formed in the crucibles are condensed in receivers, made of refractory earths and called *tubes* or *bottes*. From these the liquid metal is withdrawn, either several times during the operation or once for all at its termination, and it is immediately run into ingots or rectangular plates, of a thickness from 20 to 25 mm. (0·8 in. to 1 in.) and weighing about 20 kilos. (45 lbs.).

The first products of the distillation are collected, in the form of dust more or less oxidised, in wrought-iron pipes which form a prolongation of the tubes. This dust, to which has been given the name of gray oxide, must be submitted to a fresh treatment, unless it can be utilised directly for painting, or for making hydro-sulphite of soda. The second treatment is sometimes carried out in a furnace with vertical retorts, which bears the name of its inventor, M. Montefiore, and which is worked particularly at the Corphalie manufactory.

The ingots of raw zinc are some of them taken to a rolling mill and rolled into sheets. Others are reserved for making oxide of zinc; and others lastly, destined for different industries, such as the making of brass, are sold in the condition in which they leave the foundry.

Rolled Zinc.

The uses of rolled or sheet zinc are numerous and varied. New uses are created every day. The consumption of rolled zinc, which has long been large, increases continually, and the greatest part of

the zinc produced in Europe is not used until it has been passed through the rolls. The rolling of this metal at first encountered very great difficulties. These arose from the fact that its malleability is confined between very narrow limits of temperature. For this reason the rolling of zinc will always remain a delicate operation, which can only be entrusted to experienced hands. The most suitable temperature is about 100° C. = 212° F., and this must be maintained through the whole of the process. Below this point the metal opposes too great a resistance to the squeezing action of the rolls; and it must be re-heated, which is a matter of much inconvenience. Above this point it becomes brittle; at 200° C. = 390° F. it can be brayed in a mortar.

Whatever its method of manufacture, zinc ought to be re-melted before being rolled into sheets. The heat of fusion varies between 400° and 500° C., or 750° and 930° F. Re-melting is generally accomplished in a reverberatory furnace. Its first advantage is that it rids the zinc of the impurities, especially lead, which almost always accompany it. Again, the thickness of the ingots must vary with the final dimensions required: this is another consideration which renders re-melting indispensable.

The re-melted plates are first roughed down or rolled between heavy rolls; then, after being cut down to a fixed weight, they are taken to the finishing train, where the rolling is completed. There are therefore two distinct operations—roughing down and finishing. Between the two the sheets should be re-heated in annealing boxes, placed upon the melting furnace, so as to utilise the waste heat. Each of these operations gives rise to a production of scrap, which is more or less large according to the quality of the metal and the thinness of the sheet. This scrap, as well as any defective sheets, are re-melted with the ingots coming from the foundry. On leaving the finishing rolls, the sheets are cut by shears to a rectangular shape, and to the dimensions required by commerce. There are several systems of shears; those most used in Belgium are the lever shears and the guillotine shears. The latter, which at present have the preference in the rolling mills of the Vieille Montagne Company, cut the metal perfectly clean and exact.

After being squared, the sheets of zinc are sorted with great care. Those which are found to answer all the conditions are impressed with the stamp of the works. The thickness is specially gauged, and is expressed by a number on a fixed scale. It varies between 0·05 millimetre and 4 centimetres (0·002 in. to 1·575 in).

Zinc sheets are delivered sometimes loose, generally in barrels or boxes; hence a cooperage is an indispensable adjunct to a store for rolled zinc. This accessory is mentioned on account of its real importance.

Belgium manufactures annually nearly 40,000 tonnes of sheet zinc. The rolling mills which contribute to this production are, in the first place, those of the Vieille Montagne Company at Angleur and Tilff, which together furnish nearly 20,000 tonnes per annum. The remainder of the make is divided between the works of the Nouvelle Montagne Company, at Engis; those of the Société de Prayon, at Prayon; those of MM. Francotte-Pirlot & Co., at Chênée and Liége; those of M. E. Nagelmackers, at Chaudfontaine; those of M. Charles Heptia-Hauzeur, of Fraipont; those of Madame Veuve de Bonhomme, at Nessonvaux; those of MM. Lejeune Frères, at Stère; those of M. L. Dacier, at Liége; those of M. J. Brasseur, at Huy; and those of M. G. Schmidt, at Brussels.

As already stated, the applications of rolled zinc are numerous and varied. We will confine ourselves to a few. The making of roofing sheets certainly occupies the first rank. The systems vary according to the character of the buildings to be covered. For dwelling houses choice may be made between plates having the shape of a heart, a lozenge, a fish-scale, a rectangle, &c. All are recommended by many advantages; amongst which should be specially noted their complete impenetrability to water. Roofs for industrial buildings are generally constructed of fluted or corrugated zinc. Among other applications some of the chief are the sheathing of vessels; the making of domestic utensils and articles for various trades, for many of which the zinc must be previously pierced with holes; the glazing of paper; the making of tacks and of wire. In thick plates zinc is chiefly employed by engravers for zincography, in arsenals for fitting up shells, and in steam boilers to prevent incrustation.

OXIDE OF ZINC.

Zinc heated to a red heat is evaporated, and the vapour coming in contact with air is oxidised and produces a white impalpable substance, which alchemists named *lana philosophica*, and which in modern times bears the name of Zinc-White. This oxide has long been employed for decorative painting. Its brilliant whiteness, combined with the fact that it does not change by the action of the air, and has no ill effects on the workmen who use it, are the principal qualities which have made it the most formidable rival to white lead. In making oxide of zinc there are two processes equally simple. The sublimation process is the most ancient. To sublime or volatilise ingot zinc, it is placed in a series of retorts within a common furnace: the oxide is formed in an exhaust chimney and then passes through a long series of passages and condensing chambers. It is deposited in large tanks of sheet iron or cloth, which are ranged all along the path pursued by the vapours. At certain hours in the day the oxide is collected into casks, and then, after the quality has been tested, it is compressed into barrels carefully made, and is ready for delivery. According to the purity of the metal subjected to the process, the zinc-white obtained varies in colour and brilliancy. "Blanc de neige" is a product of the most superior quality, and can only be made with zinc from the ores of the Moresnet beds. "Blanc No. 1" is the most common variety. It requires for its manufacture zinc coming from selected ores, and generally purified by re-melting. Lastly, "Blanc No. 2" is the common variety, distinguished from the others by its shade of whiteness, though still identical in composition.

In the making of zinc-white, as in all other manufactures, residues are produced. Drops of metal imperfectly oxidised, deposit in the retorts, and waste from the workshops, are all classed separately; then after being ground, washed, and dried by being led through winding passages, they form the "gris-pierre" which is employed in painting to replace red-lead.

The second process for making zinc-white is known as the American method. It uses the ore direct, and is necessarily

cheaper therefore than the former; but its products are of inferior quality to those produced by sublimation.

There are in Belgium only two works for making zinc-white. The Vielle Montagne Company produces annually at the Valentin Cocq works 3,000 tonnes of zinc-white by sublimation. The other work is at Ougrée, and belongs to Messrs. Eschger, Ghesquière and Co. There the American method is employed, but at present the works are standing idle.

Direct Use of Ingot Zinc.

As we have said, zinc was employed in the arts long before it was known in the metallic state. As of old, the making of brass continues to absorb the largest quantities in Belgium, and above all in England. Melted zinc is also used to cast ornaments and objects of art, such as statuettes, groups, &c., which are afterwards covered with copper by means of the galvanoplastic method, and imitate bronze with a perfection which defies the most skilful eye. The Vieille Montagne Company makes from the ores of Moresnet, under the name of *fonte d'art*, a variety of zinc which is specially reserved for this purpose. Lastly, the galvanising of iron, telegraph wires, &c., is a large source of employment for ingot zinc.

If the zinc works of Belgium receive a part of their supplies of ore from abroad, in return their products are exported into all the countries of the world. France and England are those which receive the most: Germany, Italy, America, Scandinavia, and Holland, also take their share.

In conclusion, the manufacture of zinc, the origin of which in Belgium dates back to so remote a period, has received from the beginning of this century a very large development. By the number of establishments devoted to it, by the quantity and value of the production, by the multitude of workmen it employs, by the importance of the capital which it absorbs, it holds one of the foremost places in the great industrial life of the country. In spite of the depreciation in value of all metals, the production of zinc increases from year to year, and the financial results of the operation are in general

satisfactory. The working of zinc has a brilliant past, and it may be hoped that it will still enjoy in Belgium a long era of prosperity.

MAKE OF RAW ZINC IN EUROPE SINCE THE YEAR 1860.

District.	1860.	1865.	1870.	1875.	1880.	1882.
	Tonnes.	Tonnes.	Tonnes.	Tonnes.	Tonnes.	Tonnes.
Upper Silesia . .	40,354	35,430	36,518	43,123	65,437	69,846
Rhenish Provinces and Westphalia .	8592	16,647	18,006	25,396	27,107	35,546
Vieille Montagne .	28,925	30,592	42,112	41,618	44,690	48,861
Other Belgian Makers	9144	13,485	14,476	18,836	26,700	35,625
Asturias Company — Spain	1777	1325	3048	3000	4000	5047
Asturias Company — France	..	..	..	5311	8591	11,423
Other French Makers	..	500	500	1500	3000	..
England	6104	6523	16,000	15,903	22,000	25,581
Poland	1500	3000	3625	3000	4463	4544
Austria	1500	1000	1000	1000	3199	3199
Total . . .	97,896	108,502	135,285	158,687	209,187	239,672

Abstract of Discussion on Zinc Manufacture in Belgium.

M. G. ROCOUR said they had heard an admirable paper on the manufacture of zinc by M. St. Paul de Sinçay, and he wished to be foremost in recognising its value. It had been suggested however that the technical details of the metallurgy had not been very largely dealt with. It might be thought, as the trade was of a very special character, and in great measure limited to Belgium, it was not desirable or fair to extend the knowledge of it to foreigners. He was himself of a contrary opinion, especially since an explanation of the metallurgical details would show how many difficulties attended the process, and would prepare enquirers for the statement how poor the financial results had latterly been in many cases, notwithstanding the great ability of the workmen, the excellent appliances used, and the large capital at the disposal of the makers. He might begin by saying that in Belgium they were largely dependent upon foreign ores. The origin of zinc-making in Belgium was in connection with her own mines; but it was now for the most part carried on by means of foreign ores. As the paper stated, in 1882 the production in Belgium was about 83,000 tons and the foreign imports of ore were more than double that quantity, the yield being at least 40 per cent. The price of ore was almost always increasing relatively, and the competition of the several works was so sharp that the margin of profit was a very small one. Owing to this competition the habit had arisen of buying ore from the mining companies on contract for many years forward, with a fixed minimum of price. As the quotations in the open market were now almost always below these minimum rates, the mining companies pushed their production of ore to the uttermost. This ore the smelting companies were obliged by the terms of their contract to accept, and the result was to bring down the price of the metal below the rate at which a profit could be realised, and much below that which would rule under ordinary economic conditions. In fact it would be found that during the last three years the result

of the total working, in the leading smelting companies, had been a loss, taking into consideration the value of the shares at the present time and not simply the dividends distributed.

The metallurgy of zinc seemed to those not accustomed to it to be a very rough process. The Vieille Montagne Company had been kind enough to open their works at Angleur to the Institution, and it might seem to those who would visit them, on a superficial inspection, that nothing was so simple as zinc manufacture and nothing so easy to carry out in any country. That however was not the case. A zinc-smelting plant consisted of several rows of retorts, placed one above the other and heated by one or two furnaces. The work of charging was of a very difficult character. He thought it was more difficult than any kind of labour in iron-making. It needed a special class of workmen: and in order to keep up the regularity of the heat and the continuity of the work the men could scarcely have any holiday. Indeed he knew of works where the men had to work 350 days in the year. That, he thought, would render the industry very difficult to carry out in England.

One of the most important points of improvement had been the introduction of retorts made by hydraulic pressure, as introduced by M. Dor, of MM. de Laminne's works. The system was very effective, and the Vieille Montagne Company had adopted it, together with the crucible boring machine invented by M. Vapart, manager of the Angleur Works. By means of the press a pressure of 3000 lbs. per sq. in. could be put upon the retort; it was thus made very thin, and yet had great durability. With regard to the fires a most important modification had taken place. Gas furnaces had been adopted first in Silesia, and were now extensively applied in Belgium. By these the consumption of coal had been so much reduced, and the quality and the price of the coal so much lowered, that the advantage on the side of the Swansea works over the Belgian works, estimated twelve years ago at 15 francs per ton of ore, was now not more than 6 francs—the difference in freight to Swansea and to Antwerp being taken into account. This advantage was largely balanced by the lower cost of labour, except for spelter sold on the spot without freight expenses.

Prof. W. CHANDLER ROBERTS, F.R.S., had listened with the greatest possible interest to the paper itself, and to the remarks by which it had been followed. Whatever view might be taken as to the immediate prospects of the zinc industry in Belgium, there could be no question that the Belgian method of manufacture had displaced the English, and had found a home in Swansea. He had recently visited some large works there, at which the Belgian system was entirely adopted. A very large staff of workmen, almost entirely Belgian, was employed; and the proprietors fully endorsed the views that had been expressed as to the skill, industry, intelligence, and discipline of the men. There were one or two little details with regard to which he should like to be informed. The great difficulty that had been experienced in the use of regenerative furnaces, as applied to the metallurgy of zinc, had, he believed, arisen from the occasional fracture of retorts, giving rise to the escape of zinc, which rapidly became oxidised and choked the regenerators. He should be glad to know whether that difficulty still existed; and also whether the experiments on the extraction of zinc in blast-furnaces had been continued, and if so what measure of success had attended them.

Mr. T. B. SHARP said he would just refer for a moment to two points which had occurred to him during the reading of the paper: namely, the shape of the ingots of zinc or spelter as sent into commerce, and the loss of the oxide of zinc in the manufacture of brass.

For some reason spelter manufacturers invariably cast their ingots in large flat cakes about an inch thick, and many of the brands (one of the exceptions being that of the Vieille Montagne Company) had flakes of lead adhering to the underside of the cakes in a mechanically inseparable form. Now the evil effects of this lead in certain qualities of brass were just as serious as its separation from the zinc was easy. Its presence in the alloys of copper and zinc, which was known without analysis by the whiteness of their fracture, rendered them quite rotten for resisting bending or torsion, and weak for resisting tensile strains: while the alloys

containing it, when exposed to sea water or to dirty water containing acid impurities, wore badly and irregularly, owing to its uneven distribution throughout the alloy. Now in order to make sure of the separation of the injurious lead from the zinc, he would suggest that the metal be poured, at a heat just below the volatilising point of zinc, into thick vertical moulds, slightly rounded at the bottom to prevent cracking; it would then be found (provided the moulds had been well heated before the operation and were allowed to cool slowly afterwards) that a complete separation of the metals was the result. He had himself adopted this plan for the separation of the lead in the residuum from old zinc furnaces, and with invariable success: the lead being all together at the bottom of the casting, in a mass which could be readily detached by a blow from a hammer.

Next, with regard to the collection of the oxide of zinc, he had about ten years ago brought out and put to work in Birmingham a method of injecting all that went up the stack into water, by means of a modification of Giffard's injector. He had a large vat, into and out of which water was continually flowing, so as not to get too hot. The level of this water was constant, and about 4 in. below its surface was a perforated plate; and down a large tube communicating between the top of the stack and the underside of this plate, all the products of combustion, including of course the valuable oxide, were driven by the lateral or inductive action of a jet of steam. The result was that the products of combustion rose through the water in minute bubbles and streamlets, and passed away in an almost colourless gas, after having parted with the zinc white and unconsumed particles of carbon, which remained in the water in the form of a grey mud. This mud was then recovered by subsidence, and finally reduced in the ordinary way. He had found that 40 lbs. was the most suitable pressure for the steam; but it was required in such large quantities that, although in the works where he had started his plan the loss of zinc was estimated at over £5000 annually, and although he had succeeded in recovering over 90 per cent. of the loss from the furnace to which he had applied his apparatus, it was found that the cost of producing the steam was so great as to absorb the profits of the undertaking. His reason for describing this

plan was that, though he himself had rendered it only a scientific success, he still believed that, where the steam could be had for very little (say from the waste heat of furnaces), it could also be rendered a commercial success. Air furnaces for making brass however could not be used for producing their own steam, and that for many reasons: two of which were that the oxide quickly deposited on the comparatively cool plates of the boiler, rendering the heating surface inoperative, and that the draught was so much interfered with that an uncertain alloy resulted. Now this question of the loss of the zinc through volatilisation and oxidation was another reason why the round-bar form (and he would here suggest a diameter of three or four inches) was the best for the ingot. The bars of zinc could then be dropped vertically into the metal by means of a pair of specially constructed claws: which would cause much less loss than the present plan of placing a number of cakes on the top of the metal. The whole, he considered, was simply a question of relative proportion between surface and cubic capacity; and of course the circular shape gave the least surface for the greatest weight. He saw only one objection to these circular rods, namely the difficulty of breaking them up for make-weights; but for this purpose a smaller diameter, say about 1¼ in., could be used. Of course there must always be some loss in working; but he felt convinced that if any spelter manufacturer would take up the circular bar form it would soon be appreciated by users, inasmuch as, other things being equal, the loss of zinc would be materially reduced.

M. ROCOUR said, in regard to the breaking of retorts, it was generally found that a clay retort stood much better with the use of a gas generator than with the old fires. As to the use of the blast-furnace for zinc, that system had been tried several times in Belgium, but not during the last 25 or 30 years. Several trials had been made, one by Prof. Lesoinne, of the School of Mines of Liége, and another by MM. Muller and Lencarchez, but the plan had never succeeded. The reason was very simple, viz. that, if a current of vapour of zinc and gases contained only a trace of carbonic acid, the zinc reduced the carbonic acid, so that there was left only a

mixture of carbonic oxide and oxide of zinc. He did not know any kind of furnace that could meet this difficulty. In the present state of technical science he believed the problem was quite insoluble. There was another reason also, arising from the difficulty of condensation, when there was a rather small quantity of zinc vapour mixed with a very large amount of other gas. That was another drawback; but the first was quite sufficient to negative any other method of reducing zinc than in a retort.

The CHAIRMAN said he was quite sure they would all be pleased to return to M. St. Paul de Sinçay a hearty vote of thanks for the paper which had been read; and to this he would add a hearty vote of thanks to M. Rocour for standing sponsor to the paper in M. de Sinçay's unavoidable absence, and for giving such an able account of some of the technical details in the manufacture of zinc. They would see the system more fully in operation during their visit; and what they had heard would serve as an excellent introduction to their inspection of the works at which the process was carried out.

ON THE MANUFACTURE OF SUGAR IN BELGIUM.

BY M. A. MELIN, OF WANZE.

RAW MATERIAL.

The raw material from which sugar is made in Belgium is the Beet-root. This plant, which is indigenous to the south of Europe, in Spain, Portugal, &c., was imported into Belgium in the 16th century. It was only however in the last century that its cultivation became extensive; this was in consequence of the continental blockade, which made it necessary that Belgium should manufacture her own sugar, so as to replace that which had formerly come exclusively from the Colonies.

A good sugar beet-root does not exceed 1 kilogramme (2·2 lbs.) in weight, and in general weighs from 400 to 700 grammes. Beyond the latter figure, and without exception, the larger it becomes the less rich is it in sugar. The roots richest in sugar are always found of a weight between 400 and 500 grammes; below 400 grammes the quality becomes inferior; the weight is abnormal, and shows a tendency to disease, or the occurrence of some hindrance to the growth of the root. In general the purity of the juice goes hand in hand with its richness, the exceptions to this rule being rare. The best shape is that of an elongated pear, regular in form, not forked, and without lateral rootlets; the flesh is white, dense, opaque and brittle; the head is small, and rises but a short distance out of the ground. A fact confirmed by thousands of analyses is that, other conditions remaining the same, the white varieties are richer in sugar than the red; and similarly the elongated form is superior to the round form in this particular.

As to soil, beet-root will grow in any soil, but that which suits it

the best is an earth of moderate consistency. The one condition which is indispensable for the success of all sugar-bearing roots is an earth which is deep and a sub-soil which is permeable to moisture, for they are eminently disposed to send out tap-roots.

It is usual in Belgium to make beet-root the first crop in the course of agriculture, so as to receive the first effect of the manure. The two-year course, beet-root and barley, is but little used; the four-year course, beet-root, barley, clover, barley, is perhaps the most common. At the Agricultural Institute in Gembloux the course is as follows—beet-root, barley, clover, barley, beet-root, barley. Sometimes a three-year course, beet-root, barley, clover, is used; but in this case the beet-root has a disadvantage in following the clover. Regular courses of this kind are only adhered to by good farmers.

The manures ordinarily employed for beet-root are the common refuse of the farm, assisted by chemical manures; the quantities depend often upon those which are at the disposal of the farmer. Good farmers ordinarily apply 30,000 or 40,000 or 50,000 kilogrammes to the hectare (12 to 20 tons per acre), together with 500 to 600 kilogrammes of artificial manure (4 to 5 cwt. per acre). Such manures generally contain 4 to 5 per cent. of assimilable nitric and ammoniacal compounds; 5 to 6 per cent. of assimilable phosphoric acid (mono-calcic or bi-calcic); and 6 to 8 per cent. of potash. This manure is quite sufficient both as to quantity and quality. To this is often added a certain quantity—10,000 to 20,000 kilogrammes per hectare, or 4 to 8 tons per acre—of scum, &c. from the sugar works themselves, which forms an excellent manure.

The farm manure is ploughed in in the ordinary way; the chemical manures are always applied in the spring, and buried less deep. They are scattered broadcast over the last harrowing but one, and covered in by the last. As we have said, the beet-root receives the first effects of the manure; as its vegetation is of short duration, it is indispensable, especially as regards quality, that the farm manures should be applied before the winter comes on, in order that their decomposition may be as advanced as possible.

Numerous experiments have shown the results of manuring to be as follows:—

I. A powerful manure, especially if slowly applied, augments the quantity to the disadvantage of the quality of the product, as to quantity of sugar and purity of juice.

II. Manures rich in nitrogen have a similar effect.

III. Manures containing potash, although they bring in an element which is harmful in the manufacture, are indispensable for the development of the sugar, as well as for the growth of the root.

IV. Phosphates have an excellent effect on the quality of the beet-root.

V. Lime appears to have a remarkable effect on the purity of the juice, as well as on its richness in sugar.

As to the preparation of the soil, good farmers after the harvest are accustomed to plough their land slightly, in preparation for beet-root. The object is to make the seeds of grass &c. germinate, in order that they may be destroyed at a later period. They then apply the manure, and plough again before the winter. This ploughing is especially useful for heavy soils, since, in addition to advancing the decomposition of the manure, it exposes the ground to the frost, so that it is broken up in a way that no mechanical means could ensure. Some days after ploughing afresh in the spring, the ground is harrowed and rolled alternately, until the soil is perfectly broken up, after which the sowing is done upon the last harrowing.

In Belgium sowing takes place about the second half of April. The young plants spring up about the beginning of May; and have thus nothing to fear from late frosts.

Good farmers experiment on their seed before sowing, in order to ascertain its germinating powers. Special germinators, of which that of Nobbe is most in use, are employed for the purpose, or mere earthenware pots filled with earth. The conditions indispensable to germination are air, warmth, and moisture; the most suitable temperature is from 59° to 72° Fahr. Good seed will give 80 to 90 per cent. of germinated grains within ten days. If the number falls below 70 per cent. the seed is of doubtful character, due either to damage or to adulteration.

Seed which has been thus tested is sown by means of sowing

machines, of which that most in use is the spoon machine of Smyth.

The space between the rows is 35, 40, or 45 centimetres (14, 16, or 18 in.), and the depth of sowing 3 to 4 centimetres (1 to 1½ in.). In each row the plants are at distances of 25, 28, and 30 centimetres (10, 11, and 12 in.). During the sowing a labourer leads the horse by hand, a precaution necessary to get the lines straight and thereby render possible the operations to be subsequently performed by means of horses.

Experiments made at the Agricultural Institute of Gembloux give the following results:—

I. A distance of 40 centimetres (16 in.) between the lines, and 25 centimetres (10 in.) between the plants, is especially to be recommended, both as regards weight and richness in sugar of the crop.

II. By adopting these distances, in place of 45 centimetres (18 in.) and 30 centimetres (12 in.), which are most common in Belgium, and by selling his crop upon analysis, the farmer will obtain not only a larger return per acre, but will produce superior beet-root and do real justice to the industry he follows.

As to the quantity to be sown, it was formerly 15 kilogrammes per hectare (13 lbs. per acre); but at that time gaps were numerous in the sowing, and at present 20 to 25 kilogrammes (18 to 22 lb.) are employed. Theoretically this quantity is perhaps ten times too great; but the amount of seed thus spent is much more than recouped by the crop obtained.

A roller follows the sower and covers in the grain. As soon as the plants spring out of the soil, the farmer begins a series of hoeings, which succeed each other at intervals more or less short. The number cannot be determined beforehand, for in moist and hot years, when weeds grow apace, it is often necessary to begin a second hoeing before the first is ended. A horse-hoe is employed. The destruction of the weeds should be completed by repeated weedings, which should commence as soon as possible. The longer the delay the greater the growth of the weeds, and the greater the inconvenience of their removal.

These hoeings and weedings have a double aim, first the complete breaking up of the soil, secondly the destruction of the weeds.

We have seen that to avoid gaps more seed is sown than is required. This seed springs up thickly and in a continuous row, but as the roots are to be spaced 25 to 30 centimetres apart (10 to 12 in.), a clearing is necessary. This clearing is done roughly by hoes, and afterwards completed by hand; the latter is a delicate operation which requires much care. Children move over the field on their knees and pluck up the superfluous plants. They leave one at each 30 centimetres, trying always to preserve the finest plants. This operation should be carried out as soon as possible, for the superfluous plants act the part of weeds. They may also entangle their rootlets with those of the plants to be left, which produces disease and deformity in the latter.

The beet-root has a tendency to become an annual plant; hence every year some plants scattered over the field are seen to run to seed. These stalks must be removed, since the root becomes tough, and partially loses its sugar.

The beet-root becomes ripe about the end of October, but economical reasons require its being pulled from the 15th to the 30th September, so that all which cannot be worked up at once may be placed in silos. They are pulled by hand, the labourers drawing the roots from the earth and laying them on the ground. Others follow, pick up the roots, and cut off the top with a knife. The tops and leaves remain on the ground for manure. The roots, thus lopped and freed from the earth hanging about them, are placed upon wagons, which transport them to the sugar works.

The amount of the crop varies exceedingly, depending on the nature of the soil, of the seed, of the cultivation, of the weather, &c. On an average a crop of 40,000 kilogrammes per hectare (16 tons per acre) may be expected, with a richness in sugar varying from 9 to 11 per cent. Crops are frequently met with however of 60,000 to 70,000 or even 80,000 kilogrammes to the hectare (24, 28, and 32 tons per acre), but in such cases the richness of the sugar falls from 9 down to 7½ per cent.

To obtain seed, when it is desired to make sure of its quality, a certain quantity of roots, which are chosen as the finest, are preserved in silos or in cellars, and are carefully looked after. In the spring these roots are replanted, and they run to seed the same year.

Such roots should be chosen from those which are the richest in sugar; they will give seed suitable for reproducing beet-root of good quality, their properties being transmitted from one generation to another. This choice is not easy to make, for the richness must be judged of without destroying the root, inasmuch as it has to be replanted in order to give seed.

Many farmers choose their seeding roots by throwing them into a pan of water mixed with sea-salt, and raised to a density of about 1·05. Some of the roots swim, being less dense than the liquid, and these are rejected as ill suited for reproduction. The others sink; these are the best, and are preserved for seed. The principle in this method is that the densest roots are the richest in sugar. The principle is correct, but cannot be rigorously applied: there are numerous failures, chiefly due to the fact that the tops are not all cut at the same level, and that those roots which have more top have a tendency to float, although they may be of excellent quality.

Another process, more sure in its effects than the last, consists in analysing a part of the root, leaving it in a state in which it will still grow after being replanted. M. Vilmorin, the author of the process, uses for this purpose a probe like a cheese-taster, a small copper cup lined with silver, a rasp, a meter for density, a thermometer, and a gauge. By means of the probe he takes a cylinder of flesh from the centre of the beet-root. This is rasped up, pressed in a linen cloth, and the juice run into the gauge. The temperature and density of this juice are taken, and then by special tables an approximation can be made to the richness in sugar of the beet-root operated upon. The principle here is the same as in the previous method, namely that a denser juice is richer in sugar. It is however a long process, scarcely practicable on a large scale; its advantage is that it operates on the centre of the beet-root apart from its outside, but it is still only approximate on account of the dry constituents, which though free from sugar equally affect the measure

of density. The beet-roots being thus chosen for seed, the hole left by the probe is filled up with clay, and the roots are preserved out of the reach of the frost until the spring, when they are replanted.

For the cultivation of the seed the land is made ready as for ordinary sowing. In April the selected roots are replanted at distances of 60, 80, or 100 centimetres from each other (24, 32, or 40 in.), and in lines. The field ought to be at a distance from any other field which contains other seeding plants, otherwise a mixture might take place to the damage of the beet-root. These plants become very strong, especially in good soil. Under the weight of the seed they are very apt to turn over, which is avoided by the use of supports. The seed is ripe in September. To gather it one ought not to wait until all the seeds are ripe, as the finest might thus be lost. The stalks are cut whilst the seed is still half ripe. They are tied up in bundles, and hung in a sheltered spot fully exposed to the air. With a space of one metre (40 in.) between the plants, the return will be 200 to 250 grammes (7 to 9 oz.) of seed per plant, or 2,000 kilogrammes per hectare (16 cwt. per acre).

Analysis of the Substances occurring in the Manufacture of Beet-root Sugar.

From the industrial point of view it is necessary to remember the following facts :—First, 100 kilogrammes of good beet-root contain approximately and in round numbers 95 kilos. of juice, and 5 kilos. of cellulose substance : secondly, these 95 kilos. of juice contain 10 kilos. of crystallisable sugar, 2 kilos. of solid matter not containing sugar, and 83 kilos. of water. In manufacturing, the point to be specially ascertained is the percentage of sugar, for on this depends the value of the beet-root. There is however another point of great importance, namely the purity of the juice; the latter depends on the less or greater quantity of matter free from sugar which is dissolved in the juice with the sugar itself.

The following is the process for ascertaining the percentage of sugar. The roots, properly washed, lopped, and dried, are scraped into pulp with a small special rasp; the pulp is squeezed in a special

screw press, and the juice drawn off into a glass vessel. Into this juice is plunged a special hydrometer, which gives the total weight of matter, sugar or otherwise, which is dissolved in 100 grammes of the liquid. This figure, say 14, is noted. A hollow ball of glass, gauged to 100 to 110 cubic centimetres, is filled with this juice up to the 100 mark, and then 10 c.c. of sub-acetate of lead is added; the two are shaken up together and filtered. With the filtered liquid you fill a polarimeter about 200 mm. long, and polarise. Suppose that the polarimeter has the normal weight of 0·162 gramme per degree, and that the juice gives a polarisation of 69 degrees. Here it must be remembered that the figure 69 is below the true figure, because we have added to 100 c.c. of juice 10 c.c. of the qualifying liquid, sub-acetate of lead. The liquid has thus been diluted by one-tenth, and would have otherwise have polarised $69 + \frac{1}{10}$ of $69 = 75 \cdot 9$ degrees. It follows then that in 100 c.c. of the liquid there are $75 \cdot 9 \times 0 \cdot 162$ grammes of pure sugar, or 12·29 grammes. But as we know the total quantity of matter dissolved in 100 grammes, and not in 100 c.c., of the juice, we must determine the sugar thus contained in 100 grammes. By means of special tables we find that the figure 14 given by the hydrometer corresponds to a specific gravity of the juice equal to 1·057. Hence we have the following proportion. If 100 c.c. of juice weighing 105·7 grammes contain 12·29 grammes of sugar, the volume corresponding to 100 grammes will contain $\frac{1229}{105 \cdot 7} = 11 \cdot 63$ grammes of sugar per 100 grammes of juice. We now have as follows:

	Grammes.
Total solid matter in 100 gr. of juice (by the hydrometer) .	14
Pure sugar in 100 gr. of juice (by the polarimeter) . . .	11·63
Difference, or solid matter free from sugar	2·37

These two figures express the purity of the juice. For if in 14 parts of solid matter there are 11·63 of sugar, 100 parts of solid matter will give $\frac{1163}{14} = 83 \cdot 07$ per cent., as the "quotient of purity," that is the percentage of sugar contained in the whole of the solid matter in solution. In beet-root the purity generally varies between

75 and 90 per cent.; if it falls below 75 per cent. the beet-root is considered unsuitable for the manufacture of sugar.

In order to know the amount of sugar in the beet-root, we have only to remember that the root contains 95 per cent. of juice; hence, since 100 grammes of juice give 11·63 of sugar, 95 grammes of juice, or 100 grammes of beet-root, will give 11·05 of sugar.

The richness in sugar and the purity being the two essential qualities in beet-root juice, they have been united together in a single "standard of value:" this standard is merely the product of the two factors, namely the percentage by weight of sugar in the juice and the quotient of purity. In the example given this product will be $11 \cdot 63 \times 0 \cdot 8307 = 9 \cdot 66$. It is not common to make any further investigations, unless into the quantity of ash and glucose.

We may now pass on to the products of manufacture. The first to be considered is the Raw Juice (as obtained by pressing the pulp), which is nothing but the natural juice of the beet-root with the addition of a certain quantity of water, say 20 to 30 per cent. of the beet-root weight; the analysis of this juice is therefore identical with that of the beet-root juice already discussed. If when analysed it is already mixed with lime, it must be treated with acetic acid, before adding the clarifier, so as to neutralise the lime completely; otherwise this would falsify the reading of the polarimeter and give results below the truth.

In order to ascertain the progress of the juice towards purification, in the course of manufacture, analyses are made of the carbonated juice and filtered juice, as well as of the syrup before and after filtration. The juice is analysed as before, the small quantity of lime which it contains being previously neutralised. The investigation is merely into the purity of the juice, with the object of regulating the method of working.

With regard to the syrups, they are much richer than the juice, and contain more than 16·2 per cent. of sugar, a quantity which corresponds with 100 degrees of the polarimeter or with the top of its scale: hence it is impossible to operate on 100 c.c. of the syrup, as in the case of the raw juice. It is therefore usual to take 50 or 25 c.c. of this concentrated juice, and to add water enough to make

it up to 100 c.c. When reading off, this dilution will be taken into account by doubling or quadrupling the reading of the polarimeter.

Next comes the "Boiled Mass" (masse cuite), Nos. 1, 2, and 3. In these products it is usual to analyse :—

1st. The crystallisable sugar.

2nd. The ash.

3rd. The water.

4th. The organic matter free from sugar.

From these data the quotient of purity of the boiled mass is calculated; sometimes the uncrystallisable sugar is also determined.

To determine the crystallisable sugar, let us suppose the normal weight of the polarimeter to be 16·2 grammes; in other words that 16·2 grammes of pure sugar dissolved in distilled water to the amount of 100 c.c. of sugar and water together, and polarised in a tube 200 mm. long, will make the instrument read 100 degrees. If we now take 16·2 grammes of the boiled mass, and dissolve them in water, making a total of 100 c.c., with the addition of some drops of sub-acetate of lead, and if we filter and polarise them, the liquid will give a figure corresponding to the percentage of sugar in the boiled mass, the other matters having no action on the polarimeter. The No. 1 mass generally gives from 80 to 84 per cent. by weight of crystallisable sugar.

To gauge the ash, 5 grammes of the mass are weighed in a platinum crucible, 10 drops of concentrated pure sulphuric acid are added, and the mixture is calcined in a muffle heated to a dull red heat. This gives a perfectly white ash, which is weighed. It must be remembered that the sulphuric acid has been added in order to transform into sulphates the alkaline carbonates which would have been difficult to burn. Experiment has proved that the ash thus treated weighs about one-tenth more than where no sulphuric acid has been added; hence after determining the weight of the ash 10 per cent. is subtracted in order to obtain the true ash, the gross quantity being called the sulphuric ash. Thus 0·300 gramme of sulphuric ash would give $0 \cdot 300 - 0 \cdot 030 = 0 \cdot 27$ gramme of true ash. As this ash corresponds to 5 grammes of the substance first weighed, it follows that in 100 grammes there will be $0 \cdot 27 \times 20 = 5 \cdot 4$ per

cent. of ash. The boiled mass No. 1 generally contains 4·5 to 5·5 per cent., or 5 per cent. on the average.

To ascertain the water, 5 grammes of the substance are weighed and dried in a hot-air stove for several hours, at a heat of 100° to 105° Cent., until they lose weight no longer. The weight lost represents the water in 5 grammes of the substance, and must be multiplied by 20 to give the percentage. Generally there is 5 to 6 per cent. of water in the mass No. 1.

To ascertain the unknown organic matters no analyses are made; they are determined by the method of difference. Thus, suppose we have—

	Per cent.
Crystallisable sugar	83·00
Ash	5·00
Water	5·50
Organic matter will be	6·50
Total	100·00
The total amount of solid matter in solution being	94·50

With regard to the quotient of purity, it will be remembered that the purity is determined by the ratio of the sugar to the total amount of matter in solution. It now therefore becomes easy to determine this ratio. We have sugar = 83·00 per cent., total matter in solution (crystallisable sugar, ash, and organic matter) = 94·50 per cent.: hence the quotient of purity $= \frac{8300}{94 \cdot 50} = 87 \cdot 84$ per cent. The ordinary figure for mass No. 1 is 87 to 90 per cent.

The quantities indicated for taking samples need not of course be exactly as stated. They may be selected at convenience, and the percentages afterwards calculated.

The masses Nos. 2 and 3 are subjected to analysis in the same way as No. 1. They are naturally less rich and more impure than the latter. The approximate constitution will be as follows:—

Mass No. 2.	Per cent.	Mass No. 3.	Per cent.
Crystallisable sugar	67·00	Crystallisable sugar	58·00
Ash	10·50	Ash	14·00
Water	11·50	Water	12·00
Organic matter	11·00	Organic matter	16·00
Quotient of purity	75·76	Quotient of purity	65·91

The final molasses, left after the treatment of mass No. 3, are analysed in the same manner.

After the treatment of mass No. 2, it is no longer possible to discolour the liquid sufficiently by means of sub-acetate of lead alone; therefore, after taking a sample and dissolving it, some drops of sub-acetate of lead are added, and twice as many drops of solution of tannin in alcohol, the proportion of tannin being 20 per cent. The approximate figures for these final molasses are as follows:—

Density (by Baumé densimeter)	42·17
	Per cent.
Crystallisable sugar	47·17
Ash	13·17
Water	24·52
Organic matter, &c.	15·14
Quotient of purity	62·27.

We now proceed to the analysis of the sugar. In raw sugar it is usual to ascertain—

1st. The crystallisable sugar.
2nd. The uncrystallisable sugar.
3rd. The ash.
4th. The water.
5th. The organic matter free from sugar.

From the three first of these the commercial value of the sugar can be calculated.

To ascertain the quantity of crystallisable sugar contained in a raw sugar, a weight equal to the normal weight of the polarimeter is dissolved in a vessel gauged to 100 c.c., with the addition of a little water. To this are added 10 drops of sub-acetate of lead and 20 drops of tannin prepared as described above; the volume of 100 c.c. is made up with pure water. The clear juice is shaken up, filtered, and polarised. If it polarises 95 degrees, this indicates that it contains 95 per cent. of pure sugar, the remaining 5 per cent. being due to moisture, ash, and organic matter free from sugar.

There always exists in raw sugar a small quantity of uncrystallisable sugar: this is tested by means of a definite cupro-potassic solution. This liquid, which is blue, is completely discoloured when hot by a

solution of uncrystallisable sugar. The same juice is employed as in polarising the crystallisable sugar. The amount of this juice which has been required to discolour a known quantity of the cupro-potassic solution, gives the percentage of the uncrystallisable sugar contained in the raw sugar.

The ash is ascertained by burning in a platinum crucible, heated in a muffle to a dark red, 5 grammes of sugar moistened with a few drops of pure sulphuric acid at 66 degrees. The ash resulting from the calcination is weighed, and one-tenth the weight subtracted; the remainder multiplied by 20 represents the percentage of ash.

The water is found by drying at 100° C., in a hot-air stove, 5 grammes of sugar; the loss in weight multiplied by 20 gives the percentage of moisture.

The organic substances are ascertained by the method of difference.

It is asserted by refiners that 1 kilogramme of ash prevents the crystallisation of 5 kilos of sugar in the refinery. This is an exaggeration, but it is sanctioned by usage, and has to be accepted by the manufacturer; so that the buyer everywhere pays only for the crystallisable sugar, diminished by five times the weight of the ash, and by the weight of the uncrystallisable sugar. The result thus produced is called the "titrage."

The usual composition of Belgian sugar is in round numbers as follows:—

	Sugar No 1.	Sugar No. 2.	Sugar No. 3.
Crystallisable	96·00	92·00	90·00
Uncrystallisable	0·05	0·10	0·15
Ash	1·10	2·50	2·80
Water	1·50	2·80	3·40
Unknown matter (by difference)	1·35	2·60	3·65
	100·00	100·00	100·00

Thus the "titrage," or the percentage paid for by the buyer, will be as follows:—

Sugar No. 1 . . . $96{\cdot}00 - (0{\cdot}05 + 1{\cdot}10 \times 5) = 90{\cdot}45$

Sugar No. 2 . . . $92{\cdot}00 - (0{\cdot}10 + 2{\cdot}50 \times 5) = 79{\cdot}40$

Sugar No. 3 . . . $90{\cdot}00 - (0{\cdot}15 + 2{\cdot}80 \times 5) = 75{\cdot}85$

For sugars Nos. 2 and 3 these figures vary greatly: they are sometimes higher for No. 3 than for No. 2.

The ordinary methods of buying beet-root have an essential influence on the saccharine qualities of the root supplied by the farmer. Beet-root may be bought on various principles, as follows.

(1) By simple weight, at so much per ton, without any consideration as to the richness. This gives the buyer no guarantee whatever as to the value of his raw material, and the farmer thinks of nothing but the largest possible yield per acre. In consequence it is almost certain that the manufacturer will receive poor root, overcharged with foreign matters. This method is rapidly disappearing.

(2) By the specific gravity of the juice. This is an improvement, but gives no certainty as to richness. The density of a juice is not due exclusively to its richness in sugar; it is largely influenced by the smaller or greater proportion of saline and organic matter contained in solution. On this basis a beet-root of a density of 1·05 would be paid for at a price of say 20 francs per 1000 kilos, and this would be increased or diminished by 0·4 franc for each tenth of a degree more or less, as indicated by the densimeter. The Union of Belgian Cultivators and Manufacturers formerly proposed the following prices:—4·50 francs for 1000 kilos and for 0° of the densimeter in September; 4·00 francs from the 1st of October to the 15th of November; 4·25 francs from the 15th of November to the 5th of December; and 4·50 francs from the 5th of December to the end of the season.

Five methods are employed by the manufacturer, to secure himself against poverty in sugar and impurity, in the beet-root furnished him by the two modes of purchase just explained. These are as follows:—

(*a*) Selection of his own seed.

(*b*) Fixing the number of plants per square metre.

(*c*) Forbidding the employment of certain manures largely charged with nitrogen.

(*d*) Forbidding the application of certain manures at certain periods in the year.

(*e*) Refusing beet-root which has been grown on waste land newly cleared.

(3) According to the richness in sugar. This is more rational, and suits at once the interests of the manufacturer and the farmer. The former pays according to the intrinsic value of what he gets; the latter, though raising a smaller crop, receives a better price; he gets the advantage of a reduced cost for transport, and a smaller quantity of fertilising matter subtracted from the soil. This latter quantity varies directly as the weight of beet-root produced, and inversely as the richness of the roots in sugar. It is generally assumed that 1000 kilogrammes of beet-root carry away with them 3·9 kilogrammes of potash, 1·6 of nitrogen, and 0·8 of phosphoric acid. On this system beet-root would be bought at 22 francs per 1000 kg. if containing 11 per cent. of sugar, and this price would be increased or diminished by 1½ to 2 francs for every 1 per cent. that the richness was above or below this amount. This is becoming the general method of buying.

(4) By the standard of value, which, as we have explained, means the product of the percentage of sugar in the juice multiplied by the quotient of purity. This is superior to all other methods, and gives the manufacturer all he can require. Being based both on the richness and the quotient of purity, it takes into account the relation between the saccharine value and the quantity of foreign matters, organic and inorganic, which accompany the juice. It is the combination of these two factors which constitutes the true element of industrial efficiency. On this system the price per 1000 kg. would be calculated at a certain number of francs per unit of standard of value. M. Péterman, director of the Agricultural Institution at Gembloux, proposes the following prices:—

In September, 2·65 francs per unit of standard of value.

From the 1st October to 15th November, 2·50 fr.

From the 15th November to 15th December, 2·60 fr.

From the 15th December to end of season, 2·70 fr.

This fourth method is as yet very little employed. Naturally, in all the examples given above the prices stated will vary according to the fluctuations of demand and supply, the price of sugar, of labour, &c.

There are two difficulties which prevent the last two methods

from becoming general. These are (1) The means of arriving at an exact average sample; and (2) The objections of the farmer.

The first difficulty is not insurmountable. A sample may be taken, (*a*) on the field before carting, (*b*) on the wagons when being discharged, (*c*) on the samples used for fixing the tare. (See third paragraph below.)

The second obstacle is more difficult to overcome, being due to the farmer's mistrust, and in general to his ignorance, of the analytical processes employed.

OPERATIONS PRELIMINARY TO MANUFACTURE.

Whatever may be the mode of buying, the exact determination of the weight of beet-root is indispensable, since the price is per tonne net. For this purpose the wagons are drawn, first loaded and afterwards empty, over large 10-tonne weighing machines: the difference between the two weights gives the gross load.

To obtain the net weight, it is necessary to subtract the earth still adhering to the roots, and the injurious parts of the root itself. To do this, as each wagon is weighed, ten or twelve roots are taken off and weighed separately. They are then washed and brushed, the top cut off, together with the green part next to it, and the roots again weighed; the difference between the two weighings fixes the tare.

The Ensilage of the beet-root generally takes place at the works. It is only in exceptional cases and for special reasons that it is sometimes done on the fields, in cases when a road, open at all seasons, lies handy. The object of this ensilage is mainly to ensure that the work shall go on regularly during a given period, and to avoid any stoppages. That the silos may fulfil the proper conditions, the roots should be sheltered from the frost and from heating during winter, and should be removed from all drying action of the sun or wind before the frost begins. Formerly the silos were small holes dug in the ground, into which the beet-roots were thrust pell-mell and covered with earth. This system has altogether disappeared. The silos are now placed upon the ground, having a width of 2·50 to 3 metres (8 to 10 ft.), a height of

1·50 to 2 metres (5 to 6½ ft.), and a length as great as may be needed. There is a general tendency to diminish the number of silos by increasing the width to 10, 12, or 15 metres (30, 40, or 50 ft.), whilst preserving the same height. In this case however it is necessary to place at certain distances apart vertical shafts, in wood or iron, which allow of a circulation of cold air within the mass. These shafts rest on similar pipes laid upon the ground at the bottom of the silos, and placed end to end so as to form horizontal channels. The channels are from 1·50 to 2 metres apart, centre to centre (5 to 6½ ft.), and the shafts which terminate in them are at about the same distance. When the first frosts come on, the side walls of the silos are covered in with a layer of earth sufficient for the purpose. A proper thickness of straw or coarse hay is spread at the same time on the top. This on the one hand keeps off the frost, and on the other gives easy passage to the heat and moisture developed by the roots, which continue to ripen while in the heap.

The first operation of manufacture is to wash the beet-roots, in order to remove gravel, earth, and rootlets. The quantity of earth adhering depends chiefly upon the moisture of the soil at the moment of pulling, the character of the soil, and the shape of the roots. Good washing is of the utmost importance: it prevents the rapid wearing out of the teeth of the rasps, ensures the purity of the pulp to be given to the cattle, and prevents any change in the natural density of the juice, which is the basis of excise. The washing is generally done in two tanks placed one behind the other. The first serves to remove the mud, the second is the washer properly so-called. Each tank is formed of sheet iron, and is 3½ to 4 metres long, 1 metre wide, and 55 centimetres high (11 to 13 ft., 3 ft., and 2 ft.). They are filled to a certain height with water. In each turns a horizontal shaft, on which are fixed cast-iron bosses carrying wooden arms set spirally round them. The beet-root is thrown in at one end, and comes out at the other where the water enters. The speed is from 15 to 20 revolutions per minute. The mud and water are collected in large reservoirs, where the mud settles, forming a deposit which contains a great quantity of roots and rootlets, and forms an excellent manure.

The proportion of sugar is not reduced by the most prolonged washing.

After washing, the beet-roots are brought together by an elevator, which delivers them either upon the rasp or upon the cutter, according as the juice is to be extracted by hydraulic press, or by diffusion. Both systems are employed in Belgium. The diffusion process is the newer and begins to displace the other.

EXTRACTION OF JUICE BY HYDRAULIC PRESSURE.

The first operation is to rasp the roots, in order to break open the cells. The more of these there are opened the more complete will be the division of the pulp, and the greater the yield of juice. This yield may vary from 80 to 84 per cent. of the weight of the pure juice, or say 78 per cent. of the weight of the beet-root. From the elevator the roots fall into a hopper H, Fig. 1, Plate 30, which delivers them to the rasping drum D. Against this they are pressed forwards by two pushers P moving alternately in a horizontal direction. The forward movement of the pushers is slow and due to a cam C: the backward movement is rapid and caused by a counterweight W. The rasp is placed on a cast-iron bed-plate of great strength. The rasping drum D, Fig. 2, is composed of three discs cast upon long hollow bosses, which are keyed upon a horizontal wrought-iron shaft having a pulley at each end so as to be worked by a double belt. The diameter of the discs is 0·70 metre (28 in.), and the interval between them 0·32 metre (13 in.). These discs are grooved on their inside faces, with a circular groove close to the circumference; in these grooves are fixed longitudinal toothed strips or blades of iron or steel, Fig. 3, separated by wooden laths, and forming the cylindrical rasping surface of the drum. The teeth are 3 mm. apart (0·12 in.), and have a height of 4 mm. (0·16 in.). The two intervals formed by the three discs are thus filled up, and the whole then has the appearance of a drum in two lengths, from the surface of which project only the tips of the teeth, standing up above the laths and the discs. The rasp is covered by a sheet-iron casing to prevent the pulp from being thrown out. Its efficiency depends on the

form and size of the teeth, on their width, on the area of the drum, on the speed of revolution, and on the speed and pressure of the pushers. The finest pulp is the best, but it requires most power. The speed and area of the rasp are the two elements which chiefly influence the quantity broken up. It is always better to augment the area and diminish the speed, as the pushers can then move more slowly, and the formation of a coarse pulp is avoided. In general a rasp running at 850 to 1000 revolutions, and having a total area of 140 sq. decimetres (15 sq. ft.), will rasp 120,000 to 140,000 kilogrammes of beet-root in the 24 hours, or 1000 kilogrammes per sq. decimetre of surface (9 tons per sq. ft.). The power is estimated at 1 HP. per 10,000 or 12,000 kilogrammes treated daily (10 to 12 tons). The loss of weight in rasping is about 1 per cent. of the weight of the beet-root. A certain quantity of water is always added, varying from 20 to 30 per cent. of the weight of the beet-root. The object is to dilute the juice, render it more liquid, and thus diminish its richness, and thereby the richness of the pulp produced. The quantity of water is determined so as to give the pressed juice a density of 1·04. The rasping is the process in which the greatest quantity of water enters into the manufacture. It is indispensable to make sure of its purity, as any salts which it contains would not only injure the yield but alter the density of the juice, which is the basis of excise, and that to the prejudice of the manufacturer. In works where the pulp first pressed is again diluted, to be pressed over again, the thin juice obtained by this second pressing is used at the rasp in place of water.

The next step is to press the pulp by hydraulic pressure to extract the juice. The plant for pressing is as follows:—

(1) Four sets of woollen sacks to receive the pulp. Their dimensions are 0·80 metre by 0·50 metre (32 by 20 in.), and their weight 300 to 400 grammes (0·7 to 0·9 lb.). After six hours' use each set is sent to be washed.

(2) Screens, either of solid sheet-iron, or made of iron strips crossing each other and riveted together. These screens exceed the dimensions of the sacks by some centimetres, and form metallic diaphragms.

(3) Two preparing tables, which can be turned about a vertical shaft. They are rectangular castings with a trough around the outside, so as to collect the juice which escapes during the formation of the preliminary heaps of sacks and screens.

(4) In many cases there are two preparing presses in place of the two preparing tables. These two presses are sufficient for six hydraulic presses, and serve to begin the work of pressure, getting rid of a part of the juice before the hydraulic presses are set to work, and thus allowing the latter to move more slowly, and to keep for a longer time at the maximum pressure. These preparing presses have rapid motion but a low pressure. They are worked by gearing, and so arranged as to be automatically thrown out of gear and reversed as soon as the pile has been pressed to half its original height.

(5) A number of hydraulic presses proportional to the work to be done, and an equal number of pumps. Generally six, eight, or ten presses go to a set. Six presses will treat on an average 100,000 kilogrammes of beet-root (100 tons) in the 24 hours. The moving table of the hydraulic press is fixed upon the ram, whilst the pressure head is united to the cylinder by four strong columns. Between the table and the head is placed the pile of sacks and screens. The motion of the plungers or pumps is given by means of rods worked by eccentrics on the main shaft. These plungers are continually working, but may be made to pump or not, as required, by closing or opening a discharge valve.

The mode of action is as follows. On leaving the rasp the pulp falls into a sheet-iron vat. Two conical and self-acting scoops lift the pulp from this, and discharge it into woollen sacks, which the workmen hold in their hands. The scoops give from 15 to 20 strokes per minute. The sack when full is placed on one half of the preparing table. Its contents are made even, the mouth closed up, and the whole covered by a screen, solid or open. A preliminary pile of sacks, separated by screens, is thus formed, rising to a height of 0·40 to 0·50 metre (16 to 20 in.). The table is then swung half way round; a second pile is formed on the other half, whilst the first half is taken off and deposited on the table of the hydraulic press.

The latter can be charged with 40 to 45 sacks and screens, giving a total height of 0·85 to 0·90 metre (34 to 36 in.). The weight of pulp per sack is from 2·75 to 3 kilogrammes (6 to 7 lbs.). The press being thus loaded, the discharge cock belonging to the pump of this press is closed, the plunger forces the water under the press ram, and the latter rises until the maximum pressure is attained. The ram then ceases to rise, the pressure of water acting automatically upon the parts of the pump through a train of levers, to prevent any further inflow of water. The maximum pressure is retained as long as is considered advisable, say from 7 to 8 minutes. The discharge cock is then opened, the water is allowed to escape, and the ram of the press slowly descends. The sacks and screens are now removed; the former go to the pulp store to be emptied, and the latter return to the preparing table. The pressure in these presses varies from 150 to 200 atmospheres: it is rarely greater than 180. With a ram of 0·30 metre diameter (12 in.), or 706 sq. centimetres area (113 sq. in.), the pressure transmitted is 127,080 kilogrammes (127 tons), or 31·77 kilogrammes per sq. centimetre of the sack pressed (452 lbs. per sq. in.).

The average yield of this process, taking account of the water added during rasping, is 20 to 25 per cent. in pulp, and 90 to 100 per cent. in juice at 1·04 density, reckoning the percentage upon the weight of the beet-root. In general 100 to 105 kilogrammes of beet-root are required to produce 100 litres of juice at 1·04 density.

The richness of the pulp in sugar is from 5·50 to 7·50 per cent. in weight, the moisture from 70 to 75 per cent. in weight. The pulp is used for feeding cattle, and is much esteemed by farmers. It is preserved in holes dug in the ground, where it is strongly rammed down. The part above the surface is made to slope from all sides, and is covered in with long straw and then with a layer of earth. The sugar contained in the pulp soon begins to ferment, and this action gives a wine-like smell to the whole mass and makes it very acceptable to cattle. The value of the pulp as food is considerable. The tables of Wolff give the following results:—The ratio of nitrogenous to non-nitrogenous matter is in the pulp 1 to 10·4; in the beet-root it is 1 to 15·7; giving a proportion of 1·50 to 1 in favour

of the pulp. The money value is 2·95 fr. for the pulp, and 2·17 fr. for the beet-root; giving a proportion in favour of the pulp of 1·31 to 1. The value of the pulp as food may thus be taken as 50 per cent. more than that of beet-root.

Extraction of Juice by Diffusion.

The process of diffusion is the result of the actions known as *endosmosis* and *exosmosis*, as applied to the beet-root. These actions take place between any two liquids of different nature and density, when separated by a porous diaphragm. In the present case the liquids are pure water on one side, and on the other the beet-root juice enclosed in the cells, the walls of which are formed by vegetable membrane. To apply the process of diffusion, the roots are first cut up into slices called "cossettes," of suitable thickness, which are afterwards immersed in water. The result is that a current of *endosmosis* takes place in the water towards the juice in the cells, and a current of *exosmosis* in the juice towards the water. These currents go on cell by cell, and the effect does not come to an end until a state of equilibrium is produced between the contiguous layers of liquid. If at this moment the first water is removed and fresh water substituted, new currents begin, and a fresh quantity of sugar and of salts are extracted until another state of equilibrium results. Continuing in this way, the final result is to abstract completely the sugar and saline matter contained in the slices. On the other hand, if the water which was first in contact with the slices, and is thus already become a thin juice, is passed subsequently over slices less exhausted than the first, new currents will start, and go on until a new state of equilibrium is attained. As it advances in this way, the juice will continually increase in richness and density, encountering at each step slices less and less exhausted,—in other words more and more rich in sugar. The process going on at each instant and at any point of the diffusion battery is therefore the enriching of the juice on the one hand, and the impoverishing of the slices on the other.

The plant for this process is as follows, Figs. 11 and 12, Plates

32 and 33:—first, the root-cutter R; secondly, the diffusers D; thirdly, the heaters H; fourthly, the presses P for the slices.

The cutter, Fig. 4, Plate 31, is the machine which replaces the rasp, and divides the roots into the cossettes or slices. It is composed of a horizontal disc A, 1·40 metre in diameter (4½ ft.) having eight openings C, Fig. 5, to receive the knife-carriers, Figs. 6 to 8. These carriers are 0·40 metre long (16 in.), and carry two blades with a total cutting edge of 0·333 metre (13 in.). The disc A is fixed on a vertical shaft turned by gearing; it can be thrown out of gear so that the cutting is stopped. The cossettes fall into a sloping trough T beneath, which conducts them to the diffuser D, Fig. 4. The revolving disc A is covered by a cast-iron plate with three openings. On one of these is placed the hopper E by which the roots are introduced, and which should be high enough for the weight within it to press the beet-roots sufficiently hard against the cutting disc. The second opening is to allow of changing the knives; and the third to give access to a solid steel plate B, Fig. 8, fixed about 5 mm. (0·2 in.) above the knives, and serving to stop the beet-roots which would otherwise be carried round with the disc. This plate is called the "buttoir" or abutment. It also serves to stop the stones or other bodies which might otherwise be introduced into the cutter. The sloping spout into which the cut slices fall can be turned round its upper end, so as to be brought successively over each diffuser, without stopping the supply of the slices. Sometimes the slices fall into a chamber beneath the cutter, and are raked into the sloping spout by a scraper carried upon the bottom of the revolving vertical shaft.

The shape of the knives is very varied and even fantastic. Some have wavy edges or with sharp angles, some have a lozenge or roof shape &c. The Naprawill knives, Fig. 9, have a rectangular section, being formed of a cutting blade on which are a series of vertical projections, also having cutting edges. According to the distances between these projections will be the size of the cossettes, which are rectangular in shape. The Goller knives have a lozenge-shaped section, Fig. 10.

The ordinary dimensions for the cossettes are as follows:—Thickness, 1¾ to 2 millimetres (0·07 to 0·08 in.), or 3 to 4 millimetres (0·12 to 0·16 in.), for a width of 6 to 8 millimetres (0·24 to 0·32 in.); or thickness 1½ millimetre (0·06 in.), for a

width of 7 millimetres (0·28 in.); or thickness 2½ millimetres (0·10 in.) for a width of 4 millimetres (0·16 in.). The length varies according to the position of the beet-root at the moment it comes in contact with the knives.

The knives quickly become blunted, and generally have to be changed two or three times in the twenty-four hours. They are sharpened by the file or grindstone. The section of the cossettes ought to be clean and regular, without distortion or notches; otherwise the juice is less pure, is charged with waste pulp, and is likely to ferment.

The Diffusion Battery, Figs. 11 and 12, Plates 32 and 33, is generally composed of 10, 12, or 14 diffusers DD. They are placed either in a row, a semi-circle, or a complete circle. One 20-hectolitre diffuser (70 c. ft.) will receive a charge of 1000 to 1100 kilos (1·0 to 1·1 ton) of cossettes, and a battery of twelve diffusers will work 180,000 to 200,000 kilog. of beet-root in the twenty-four hours (188 to 200 tons). Each operation lasts from seven to eight minutes. The diffusers are cylindrical vessels with conical ends, varying in content from 15 to 25 hectolitres (50 to 90 cub. ft.). At the top is an opening for charging, covered by a lid; at the bottom is a side-door for emptying, with a false bottom sloping towards it, in order to facilitate the emptying when the door is opened. This false bottom is formed of pierced sheet-iron, and prevents the slices from being drawn into the pipes below, which carry off the juice. A similar perforated screen is placed at the top, to arrest the slices which rise on the top of the juice during the filling of the vessel with juice. There is an air cock, which is kept open all the time of the filling.

The heaters HH are cylindrical vessels 0·40 metre in diameter (16 in.), and 2 to 2½ metres in height (6½ to 8 ft.). Their ends are two perforated plates united by brass tubes; at the bottom they communicate with the diffuser behind them, and at the top with the diffuser in front. They thus serve as pipes communicating between two successive diffusers, and at the same time as heaters for the juice which traverses them. The juice passes inside the tubes, which are surrounded by steam. A thermometer placed in the upper or discharge pipe shows the temperature which the juice has attained in passing through the heater. There are three sets of pipes which

surround the battery, one set for water, one for juice, one for steam. The set for water is in communication with an air pump, so that the water may be replaced by compressed air at any instant. By means of proper valves and cocks, these pipes may be put in communication with each of the diffusers at will. The passage of the juice from one diffuser to the next is produced by the pressure of water or of air. The water pressure is given by connecting the water pipes with a tank at a height of 10, 15, or 18 metres (33 to 60 ft.). The air pressure is only used if the water supply is insufficient; it varies from $\frac{3}{4}$ to 1 atmosphere.

The slice-presses are used to extract from the cossettes the excess of water which they contain. There are four systems in general use:—(*a*) Klusemann's; (*b*) Bergreen's; (*c*) Selwig and Lange's; (*d*) the Russian pump. But none of these bring the cossettes to a condition of dryness approaching that given to the pulp by the hydraulic press. The slice-presses are generally fed with slices by means of a bucket-chain elevator, E, Fig. 11, Plate 32, to the foot of which the slices are brought by a creeper from the pit the diffusers are emptied into.

(*a*) In Klusemann's press, Fig. 15, Plate 34, a vertical cone C of perforated sheet-iron, with its smaller diameter at top, runs at 50 to 60 revolutions per minute within a fixed cylindrical casing A, which is also made of perforated sheet-iron. By means of helical blades B on the revolving cone, the slices fed in at the open top of the cylindrical casing are drawn downwards, and become thereby compressed between the cone and the cylinder. The topmost blades have their front end bent upwards, so as to subdivide the material with a view to uniformity of feed. The water squeezed out through the holes in the cone and cylinder runs away from the bottom of the press. The pressure is varied by raising or lowering, within the annular orifice left between the bottom of the revolving cone and the cylinder, an annular conical plug P carried by adjusting screws, so as more or less to throttle the escape of the pressed material from the bottom of the cylinder. Three of these presses suffice for treating 200 tons of beet-root per 24 hours, each requiring $1\frac{1}{2}$ HP. to drive it. After compression the weight of the pressed material amounts to from 35 to 40 per cent. of the weight of the beet-root.

(*b*) Bergreen's press differs from the preceding merely in having no holes in the upper portion of its pressing cone; the perforations are only in the lower portion, which carries a continuous helical blade in place of a succession of shorter blades, like those studding its upper portion.

(*c*) Selwig and Lange's press, Figs. 13 and 14, Plate 33, has two cast-iron discs D of 57 in. diameter, revolving face to face at one revolution per minute and in the same direction, but having their axes slightly inclined from the horizontal in opposite ways, so as to leave the widest space between the edges of the discs at top and the narrowest at bottom. The faces of the discs are grooved and perforated, and are themselves covered with perforated sheet-iron E. The pulp fed in at the top or widest space becomes compressed between the discs as they carry it round to the narrowest space at bottom; and on the rising side it is thrown out by a scraper S, as they release it from their grip. At the bottom, where the heaviest pressure comes on, the discs are held up to their work by six conical pressing rollers R behind them. One of these presses is sufficient for working 200 tons of beet-root per 24 hours; the driving power required is about 2 HP.

(*d*) The Russian pump is properly speaking only a feeder for supplying one or other of the above presses with material slightly drained beforehand. It consists of a horizontal cylinder, in which works a piston. During the back stroke the cylinder receives a charge of slices from a hopper above; and in its forward stroke the piston pushes the material into a perforated pipe, through which some of the water drains off. The pipe leads to a press, where the required compression is effected.

At any given moment a diffusion battery will be found in the following condition. There will be one diffuser discharging its juice to the workshops, a second being emptied and then immediately refilled, a third receiving the water pressure. In all the other diffusers the juice is in process of circulation, all the valves being open. For example, let there be ten diffusers, Nos. 1 to 10. If No. 1 is discharging its juice to the workshop, No. 2 will be emptying during half the time of each operation, and filling with fresh cossettes

during the other half. No. 3 will be receiving the water pressure; under this pressure the juice from No. 3 will pass to No. 4, that of No. 4 to No. 5, and so on up to No. 10, of which the contents are passing into No. 1. The contents of No. 1 will next pass into No. 2, which has just been filled with fresh cossettes; the juice enters No. 2 at the bottom and rises to the top, whereas in all the other diffusers the circulation goes on from top to bottom. When discharging in the next operation, the current in No. 2 will also be from top to bottom; and this reversal of the direction of motion, applied each time to the last diffuser charged, and to that only, is called "Meichage."

At this next operation then, No. 2 will send its juice to the works, No. 3 will be emptied and refilled, No. 4 will receive the water pressure; the juice will pass from 4 to 5, from 5 to 6, and so on to No. 10; from No. 10 to No. 1, and from No. 1 to No. 2; whilst No. 2 will afterwards produce the Meichage of No. 3, which has just been filled with fresh cossettes.

Thus the juice in passing from one diffuser to another continually meets with cossettes less and less exhausted, becomes thereby more and more enriched, and is finally drawn out of the last diffuser, which has just been charged with fresh cossettes. A density of about 1·04 is thus ensured to the juice. In passing from one diffuser to the next the juice traverses the heater between them.

The temperature of the juice varies from one diffuser to another, being given to it by the different heaters which it traverses. In the example here given the respective temperatures of the juice in each diffuser should be as follows:—

	Réaumur.	Fahrenheit.
In No. 1 which is discharging its juice	15°	66°
„ 2 which is being emptied, say	15°	66°
„ 3 which receives the water pressure	10° to 15°	55° to 66°
„ 4 where the juice is circulating	35° to 40°	111° to 122°
„ 5 „ „ „	50°	145°
„ 6 „ „ „	55° to 60°	156° to 167°
„ 7 „ „ „	55° to 60°	156° to 167°
„ 8 „ „ „	55° to 60°	156° to 167°
„ 9 „ „ „	35°	111°
„ 10 „ „ „	10°	55°

The juice as it leaves the diffusers is cooled to 15° R. = 66° F., although it has to be re-heated afterwards; because the excise allows no correction for excess of volume due to a temperature higher than 15° R., which is that at which the sample for excise is taken.

The yield by diffusion may be 90 to 95 per cent. of the juice contained by the beet-root. On an average it takes 90 to 95 kilos of beet-root to give a hectolitre of juice at 1·04 density (56 to 59 lbs. per cub. ft.). The quantity of cossettes left at the end is 35 to 40 per cent. of the weight of the beet-root, the amount depending much upon the presses employed and the degree of dryness of the slices. In the pressed cossettes the moisture may be taken at 88 to 90 per cent. of their weight. If, before being pressed, the cossettes are left to drain till their weight has fallen to 70 per cent. of the beet-root, the sugar they contain is from 0·30 to 0·60 per cent. of the beet-root, or from 0·43 to 0·86 per cent. of their own weight. The sugar contained in the discharged water is from 0·15 to 0·25 per cent. of the weight of the beet-root.

Péterman gives the following comparative analysis of the pulp from the hydraulic press and of the cossettes from the diffusion process, both being fresh:—

	Diffusion Process.	Pressing Process.
Water	89·91	72·48
Albumenoid matter	1·08	2·18
Fatty matter	0·08	0·30
Matter free from nitrogen	6·13	15·98
Mineral matter	0·72	3·27
Cellulose	2·08	5·79
Total	100·00	100·00

The comparison of these analyses shows that the residue from the diffusion process contains much more water and is much less rich in nutritious matter than that from the presses. A farmer therefore should not pay for cossettes containing 90 per cent. of water more than about half the price which he pays for the pulp from the hydraulic press.

Wolff gives as the ratio of the two residues as regards nutriment the following figures:—Ratio of albumenoid matter to matter free from nitrogen;—diffusion process 1 to 6·3, pressing process 1 to 10·4, (ratio of diffusion to pressing process 1·65 to 1). Money value;—

diffusion process 0·98 franc, pressing process 2·95 francs, (ratio of diffusion to pressing process 1 to 3).

Thus, when at the same degree of moisture, the cossettes give a food more rich and more nutritious than the pulp; and 100 tons of cossettes would give the same useful effect as 165 tons of the pulp from the pressure process.

The cossettes are preserved in silos like the pulp, but there is more difficulty in securing them against damage. This however may be accomplished by placing small drains at the bottom of the silos, so as to get rid of the water which runs from the cossettes under their own weight.

There are several new systems of continuous diffusers, but they are not as yet employed in Belgium.

The quantity of water employed in extracting the juice by hydraulic pressure is about equal to the weight of the beet-root. In the diffusion process the quantity of water employed is from 2¼ to 2½ times the weight of the beet-root, when water alone is used; when compressed air is used, the water can be reduced about one half. The power required for working from 100 to 125 tons of beet-root per 24 hours is from 175 to 200 HP. The coal consumption is from 2½ to 2¾ tons per ton of sugar produced.

Method of taking the Excise.

The mode employed by the Excise authorities to determine the quantity of sugar to be taxed is the following. The juice on leaving either the press or the diffuser is gauged by government officers before passing to the works. For this purpose it is run into tanks called measurers, previously gauged. Of these one is always being filled, one being emptied, and a third being cleaned. That which is being filled has its valves kept under lock and key, until the formalities relative to the taking of samples are accomplished. These consist in fixing precisely the point on the gauge corresponding to the level of the juice, and the taking of a sample to determine its density.

The law which regulates this sampling is as follows. At each measurer the charge in sugar is calculated at the rate of 1500

grammes for every 100 litres of juice, and for every degree of density on the densimeter above 100 degrees (the density of water), these figures being taken before the discharge and at a temperature of 15° R. = 66° F.; fractions below 0·1 of a degree on the densimeter are neglected. Then, to determine the quantity of sugar to be allowed for, the volume of the juice in the measurer is multiplied by the number of degrees and tenths, as shown by the densimeter, and the product by 1500 grammes. A fraction above ½ is taken as 1. Thus for a measure of 20 hectolitres and a juice of 104 degrees density, the weight would be as follows: $20 \times 4 \times 1500 = 120$ kilog.

This would be the amount of sugar taxed, the tax being 45 fr. per 100 kilog. for raw native sugar. Thus the amount of duty for 20 hectolitres of juice at 104 density would be $1 \cdot 20 \times 45 = 54$ fr.

Beet-root juice has a great tendency to spoil. Immediately after rasping, its colour deepens, and rapid fermentation would soon begin. To prevent this, as soon as the Excise operations are finished, a dose of lime is added with all speed, sufficient to preserve and purify it. If the juice is extracted at the sugar works, the juice after being limed is sent direct from the measurers to the clarifying vats. If, on the contrary, the extraction takes place at the rasping works, the juice after being limed is pumped to the central works through an underground pipe. On leaving this pipe, the juice is run at the works into new measurers, at which there are other agents of the Excise continually stationed. Their duties are merely to ascertain the volume of the juice, in order to check the volume sent from the rasping works.

SEPARATE RASPING WORKS.

In Belgium there is only one establishment with separate rasping works: this is the central establishment at Wanze, near Statte, twenty miles south-west from Liége. It possesses thirteen sets of rasping plant, nine of which extract the juice by hydraulic pressure, and four by diffusion. Two distinct sets of pipes collect the juice, one of them serving six of the raspers, the other the remaining seven. No rasping takes place at the sugar works. These pipes are buried in the ground to 0·80 metre depth (32 in.); they are laid by the side of

a road, following its windings and gradients. Their inside diameter is 0·125 metre (5 in.), whilst that of the pipes leading from each rasper to the main pipes is 0·09 metre ($3\frac{1}{2}$ in.). The main pipes have socket joints made with lead; they are of cast-iron, and are proved originally up to 15 atmospheres. The pressure within them varies according to their position from $\frac{1}{2}$ atmosphere to 10 and even 14 atmospheres. A pressure gauge in each rasping shop indicates the pressure within the pipes. Accidents by rupture of the pipes are very rare. They are made known by a depression of the gauges at the rasping shops, and by the exudation of the juice above the ground at the point of rupture. No stopping up of the pipes has ever taken place: this is prevented by flushing them for a long time with pure water before and after the season of manufacture. On the highest points of the line are placed air valves, to discharge the gases which collect there. These valves are opened daily by watchmen, who walk along the line for this purpose. On the lowest points are discharge valves, used chiefly for cleaning purposes. The juice flows through the pipes at an average speed of 2 kilometres per hour ($1\frac{1}{4}$ mile); it keeps perfectly fresh.

A telephone service unites part of the rasping shops with the central works. At the latter works the Wanze Company annually consume 100 to 115 million kilogrammes of beet-root (100,000 to 115,000 tons). The volume of juice treated each twenty-four hours is from 15,000 to 16,000 hectolitres (53,000 to 56,500 cub. ft.), corresponding to about 1,600,000 kilogrammes of beet-root (1600 tons). In 1882–3 the amount on which duty was paid was 6,500,000 kilogrammes (6500 tons), or one-twelfth of the total amount for Belgium. The distance, as the crow flies, from the central works to the different rasping works is as follows: for the first collecting main, 1730, 8650, 10,770, 20,770, 23,080, 28,080 metres; for the second, 6540, 7500, 12,115, 13,260, 17,115, 19,615, 21,923 metres. The total length of pipes is about 102 kilometres (64 miles).

DEFECATION.

The process of defecation is at once a clarifying and a purifying process, and is effected by lime. It is an operation on the perfection

of which depends the purity of the juice and the yield in sugar. In its action on the juice the lime neutralises the organic acids, and forms with most of them, as well as with phosphoric acid, compounds which in great part are precipitated. It also decomposes the salts of potassium, sodium, and ammonia: the former of these remain in solution, the latter evaporates. Magnesia and oxides of iron and of manganese are carried off with the other precipitates, being enclosed in the albuminate of lime which is formed by the coagulation of albumen under the influence of heat. As to the other nitrogenous substances, they are partially decomposed and transformed into ammonia, the penetrating odour of which is observable during the whole operation. The result of defecation is that for a juice dark brown and almost black, containing an immense amount of organic matter in suspension, is substituted a juice perfectly clear, transparent, and of amber colour. To the eye the transformation is complete, but the purification is not so perfect as might be supposed. From a purity represented by 81 to 82 per cent. the juice has attained that of 87 to 88 per cent.

The lime is not added in the form of quicklime, but in the form of milk of lime at 20° on the Baumé densimeter. The lime milk is obtained by stirring quicklime in mixers, on the bottom of which are scrapers moved by machinery. Clear water is employed, only until a thick soup is formed; then, to economise steam, the density of 20° Baumé is obtained by adding thin juice derived either from the cleaning of the filters or from the second pressing of the scum. This thin juice would in any case have to be evaporated. The lime milk is then filtered to get rid of gravel and fragments. 22 to 23 kilos of quicklime produce one hectolitre of lime milk at 20° Baumé (14 lbs. per. cub. ft.). The quantity of lime for defecation cannot be exactly stated; it varies with the nature of the juice, its composition, the period of the year, &c. As a general rule 2½ to 3 per cent. of the weight of the beet-root is sufficient in quicklime, or 12½ to 15 per cent. in milk at 20° Baumé.

Two methods of defecation are employed in Belgium:

(1) *Defecation and Saturation.*—The defecation consists in treating the juice, heated to from 60° to 70° R. (167° to 190° Fahr.), with a

proportion of lime varying from 1 to 3 per cent. as a maximum; a scum of albuminate of lime is formed, gathers together, and floats on the top of the clear purified juice, which is drawn out from beneath and sent to be saturated. The operation of saturation has as its object to take away by an injection of carbonic acid the excess of lime still contained by the clear juice from the last process. The precipitate of carbonate of lime and organic matter is allowed gradually to settle at the bottom, and the clear juice on the top is drawn off for filtration.

(2) *Double Carbonatation.*—This is a method which is becoming almost universal. In the first carbonatation the juice is heated to from 60° to 70° R. = 167° to 190° Fahr.; lime to the amount of 1 to 2 per cent. is added by successive fractions, carbonic acid being injected after each addition. The injection of gas stops when the juice has reached a fixed point of alkalisation—generally 0·10 to 0·12 per cent. of the juice in volume, but varying according to the quality of the juice. The liquor first obtained is heated, allowed to settle, and the juice drawn off from the top for the second carbonatation. This is the same operation as the last, except that the addition of lime is reduced to 0·20 or 0·30 per cent. of quicklime, and that the neutralisation by a second injection of carbonic acid is pushed much further. Generally not more than 0·02 to 0·03 of alkalisation per cent. of the juice in volume is kept at the end, and some makers go on to absolute neutrality. The liquor is allowed to settle, and the clear juice passes to the filter.

The carbonatating vats are ranged in a row, Fig. 16, Plate 35, with the settling tanks immediately beneath them, a tank under each vat; all are about the same size, and nearly cubical in shape, each being of about 40 hectolitres capacity (140 cub. ft.) for works treating 100 to 120 tons of beet-root per 24 hours. Both vats and tanks are open at the top, Figs. 17 and 18, and the bottom slopes downwards to the front for drawing off the contents. In a row of six vats and six tanks, four pairs would be for the first carbonatation and two for the second. Inside each vat, Fig. 17, is a worm of three coils of steam-pipe for heating the juice; and in the centre of the vat a pipe with perforated branches radiating from it injects the carbonic acid gas

into the liquid, which when ready is run off into the settling tank beneath. After settling here, Fig. 18, the clear juice is drawn off through a tap high enough from the bottom; and the sediment below the tap, consisting of scum and carbonate of lime, is run out through a plug in the bottom of the tank. The pipe supplying the carbonic acid gas to the vats is from 0·15 to 0·18 metre diameter (6 to 7 in.).

Manufacture of the Lime and Carbonic Acid.

In consequence of the large quantity of lime and carbonic acid introduced into the juice, importance attaches to the purity of the raw material from which they are produced. This raw material consists of limestone and washed coke.

The qualities required in the limestone are the absence of clayey matter, of sulphate of lime, of ferric oxide, of bituminous substances, of sulphur, and above all of the alkaline salts of potassium and sodium. It is known that one unit of this latter prevents five units of sugar from crystallising. In general the yield of Belgian limestone in carbonic acid is from 42 to 43 per cent. of its weight.

The washed coke should be poor in sulphur, in volatile matter, and in ash, and should have a sufficient hardness.

Despite this selection of the raw material, the richness of the carbonic acid produced in practice never surpasses 35 per cent. of the pure gas, and only attains this figure in exceptional cases. For a furnace in first-rate working order the average richness of the gas is from 28 to 32 per cent. of carbonic acid, the remainder being composed of air, carbonic oxide, nitrogen &c.

The manufacture of the lime and carbonic acid takes place in upright furnaces communicating with each other, and having the form of a frustum of a cone. They are closed at the top by a cone, which is worked at the time of charging with a little hand-winch. At the lower part are four or six discharging holes partially closed, with coke fires between them. The fires however are considered useless, and are being gradually suppressed. The lime is extracted through the holes, and conducted to the mixers to be made into lime milk.

The carbonic acid is drawn off by a blowing machine belonging to the works, through a wrought-iron tube which leads from a circular

passage constructed in the masonry of the upper part of the furnace; and from the blowing machine is delivered into the carbonatating vats. In its passage from the furnace to the blower the gas should always traverse a water scrubber, entering at the bottom and then passing through three diaphragms one above the other, which are pierced with holes and produce a continual rain. In the blower a distributing slide-valve takes the place of flap-valves.

For 1000 kilog. of beet-root, there are required 5 to 6 kilog. of washed coke and about 40 kilog. of limestone.

Treatment of the Scum.

Under the name of "scum" is comprised the crust which swims on the clear liquid in the process of defecation, as well as the deposit resulting in the settling process which follows saturation or carbonatation. This scum contains so much more juice as the settling has been more difficult; and this juice has to be separated. For this purpose an apparatus called a filtering press is employed, Fig. 21, Plate 36. It is formed of a set of square cast-iron filter plates or frames A, Fig. 19, Plate 35, in which is cut on each face a series of vertical grooves, all uniting at bottom in a common horizontal channel, also cut within the plate itself. The grooves are covered with perforated sheet-iron, and this again by a hempen cloth, both being fixed to the plate. Generally each press has a dozen plates, supported between a pair of longitudinal side-bars B, and locked together face to face between a fixed end-plate D and a movable one E, the latter being tightened up by hand-screws. In the Daneck press, Fig. 21, Plate 36, there is interposed between each plate a square wood frame C, Fig. 20, Plate 35, of the same size as the plate, but entirely open within, so as to form a narrow chamber between each two consecutive plates. Through the top rim of each cast-iron plate and wood frame is bored a circular hole F, forming a continuous channel through the whole set of plates and frames when strung together in the press; from this channel is bored a smaller hole I into the body or chamber of each wood frame. The scum to be filtered, being delivered under pressure into the channel F, enters thence into each of the chambers between the filter plates;

the liquid passes through the filter cloth into the grooves in the plates, and runs off perfectly clear through a tap G at bottom of each plate; whilst the solids it contained, such as carbonate of lime &c., are retained by the filter cloth, and form a hard and nearly dry cake in the chamber of the wood frame. When the filtering is finished, the press is unlocked, the wood frames lifted out, cleared of cake, and replaced, and the press locked together again for the next filtering.

In the Trinks press the use of intermediate wood frames is dispensed with, the cast-iron plates being made with a projecting rim all round, which thus forms the cake-chamber between the adjacent plates. In this case the scum to be filtered enters through a central hole in each plate, instead of through the top rim.

In many cases the cakes are rinsed within the press itself before being taken out, which is done either by introducing water or by a jet of steam; for this purpose a separate hole J, Figs. 19 and 20, is provided in the Daneck press through each of the cast-iron plates and wood frames, and in the Trinks press through the top corner of each plate.

Despite the pressure it is subjected to, which with a juice-pump amounts to the boiler-pressure of 4 to 5 atmospheres, the scum still contains 3 to 4 per cent. by weight of sugar. Accordingly at the present day the scum is almost everywhere subjected to fresh treatment in hot water, followed by a second pressing. This yields a scum containing about 50 per cent. only of its original content of sugar, depending upon the volume of water employed; and also a thin juice, which is mixed with that from the first pressing and is passed with it to the second carbonatation. The impoverished scum is furnished as manure to farmers, who value it much: for such uses it has a value of 6 francs per 1000 kilog.

The proportion of scum formed is from 7 to 8 per cent. of the weight of the beet-root acted upon.

FILTRATION.

The diluted juice at 5° Baumé, as it is found after defecation, is submitted to a first filtration; a second filtration takes place with the

same juice concentrated, that is to say, when it has become a syrup at 25° Baumé, and is leaving the evaporating pans—an operation which we shall describe hereafter. The filtering matter is animal charcoal, obtained by calcining in closed vessels fresh and hard bones crushed into grains of an average size of 5 mm. by 5 to 15 mm. (0·2 by 0·2 to 0·6 in.). Recently there has been much discussion as to the substitution for animal charcoal of a sort of gravel, specially prepared, with the addition of sulphuric acid so as to give a third defecation. Up to the present time this method of filtration has not gone beyond a few experiments, which are not very conclusive; and it has not succeeded in displacing animal charcoal, in spite of the high yield which it produces.

Some works manufacture charcoal themselves, as a guarantee of its quality; the greater number buy it. The charcoal chiefly acts by its surface, and therefore finer grains would be adopted, were it not for the slowness of the filtration which they produce. The action of the charcoal is chiefly to remove the lime left after saturation, the alkalis and their organic compounds, the greater part of the alkaline salts, the colouring matter, and the viscous substances. Its work is therefore to purify and to remove colour. The result is a rise in the quotient of purity of the juice, a loss of colour, a greater yield in sugar, and the obtaining of a product clearer, less brown, and less sticky. The filters employed are open or close. The former are low and wide—2·20 metres high by 1·20 metre in diameter (7¼ ft. by 4 ft.)—and work each by itself; the latter are high and narrow—4 to 5 metres high by 0·50 metre in diameter (13 to 16½ ft. by 1⅔ ft.)—and work in series, the juice passing through several filters consecutively. The passage is produced by hydraulic pressure, due to the elevation of the tank filled with juice to be filtered. Open filters are the most common.

The system of filtration varies in different works. There are the three following methods:—

I. To filter first the syrups and then the juice in the same filter.

II. To filter the syrup and juice separately.

III. To filter the syrup alone, the juice going at once to the filter presses.

The first method is defective, since the warm and diluted juice may re-dissolve part of the matter given up by the syrup. The second is the more rational one. The third is doubtful, the action of the charcoal being less energetic on the concentrated juice than when diluted.

The duration of filtering depends, first, on the quantity of charcoal in use; secondly, on its quality; thirdly, on the quantity of juice to be filtered; fourthly, on the nature of the juice. In ordinary work the duration is from nine to twelve hours. It is fixed by a trial which determines the limit of time giving useful effect.

The quantity of charcoal employed varies almost without limit, being from 3 to 30 per cent. of the weight of the beet-root. The method of defecation largely influences the quantity of charcoal required. Generally the works which use the process of defecation and saturation require much more charcoal than those which work by double carbonatation, and where the purifying by lime is carried much further. The charcoal having served for filtration, and reached the limit of useful effect of which it is capable, should be revivified in order to recover the original properties which for the moment it has lost.

This revivification of the charcoal comprises first acidulation, secondly fermentation, thirdly washing, fourthly calcination.

Acidulation is with the object of dissolving the lime and carbonate of lime withdrawn from the juice, but without dissolving the carbonate of lime which makes an integral part of the charcoal itself. The proportion of this latter must therefore be known, and the amount of chlor-hydric acid calculated which is required to bring back the proportion in carbonate of lime to that of the fresh charcoal.

The fermentation usually employed is that by hot water. It serves to destroy the nitrogenous organic matter which has been separated by the filtration, and prevent it from being reduced to carbon by calcination, and from thus filling up the pores of the charcoal and so impairing its efficiency. It is carried out in masonry vats, and lasts from seven to eight days.

The washing is carried out first in a vat, by successive renewals

of hot water, afterwards in special washers turning on trunnions, and having blades arranged in the inside in such a way as to lift up the charcoal and push it forwards in the opposite direction to a current of hot water. The charcoal is then submitted in a closed vessel to a pressure of steam, intended to get rid of its excess of water charged with organic matter, before it is delivered to the furnaces.

The revivification further includes drying and calcination. Drying is done on cast-iron plates or in kilns, heated by the waste flame from the furnaces. Calcination takes place in pipes, either of cast-iron or fire-clay, and composed of two parts. The upper one is heated directly by the flames to a temperature varying from dull red to cherry red; the lower is in the open air outside the furnace, and serves to cool the material without the contact of air. Every twenty minutes a discharge takes place, by means of slide valves which open and close the cooling pipes. On leaving the furnaces the charcoal is again submitted to treatment with steam, in order to get rid of the gas which it might still contain.

The charcoal has now become once more fit for filtration: the waste which it experiences in filtration and revivification is 4 to 5 per cent. of its weight. The waste consists, first of a powder sifted out of the charcoal when it leaves the calcining furnace, and secondly of mud deposited by settlement from the washing water.

The richness of this waste in phosphoric acid makes it an excellent manure, especially when transformed by sulphuric acid into super-phosphate. It is thus treated accordingly, either for the use of the works or else to be sold to the makers of chemical manures.

Evaporation of the Juice.

This operation has for its object to concentrate the filtered juice at 5° Baumé, and transform it into syrup at 25° Baumé. It is carried out in what are called "double-action" concentrators when there are two vessels or boilers, and "triple-action" when there are three. The principle is the same under both systems, and is that of evaporation in a vacuum. We will take a triple-action system only.

The plant consists of three vertical vessels, Fig. 23, Plate 37, each formed of a group of vertical tubes in the lower part H, a cylinder

with glass windows to it in the centre, and a dome-shaped covering at the top. The tubes are made of tinned brass and are fixed above and below to two plates of metal; the juice to be evaporated passes down through the inside of the tubes, which are surrounded by steam in a chamber H; their length is usually 1·80 m. (6 ft.).

The three vessels communicate with each other as follows:—the dome of the first communicates by a large pipe J with the tube chamber of the second, the dome of the second with the tube chamber of the third, and the dome of the third with a condenser K acting by injection of cold water.

From this arrangement it results that the admission of steam at A directly to the tubes of the first vessel produces a boiling of the juice within that vessel; the vapour thus produced warms the second, and the vapour produced in the second warms the third, whilst the vapour from the third passes to the condenser.

The condensing water, the condensed vapour, and the air are drawn off by an air-pump L worked with metal or india-rubber flap valves. In many cases a re-heater E, also tubular, is placed between the third vessel and the condenser: this effects the utilisation of part of the heat carried over by the vapour to be condensed, reduces the quantity of injection water, and so diminishes the work of the air-pump. The steam admitted directly and once for all to the first vessel is thus enabled to produce three successive effects, whence the name of triple action.

The steam employed is the exhaust steam from the various engines of the works; its temperature at 1¼ atmospheres is 106° to 108° Cent. (223° to 227° Fahr.). In consequence the ebullition would stop at the second vessel if a certain degree of vacuum did not exist in the two latter vessels; this produces a difference of temperature, between that of the steam and that of the boiling liquid in these vessels, sufficient to continue the ebullition. This vacuum, which is thus indispensable, is obtained in the third vessel by the direct action of the condenser, and in the second through the tubes in the third, which act as a surface condenser for the vapour from the second vessel. The group of tubes in the second acts equally as a surface condenser for the vapour from the first. The tubes of the

second and third vessel also communicate by small pipes with the water condenser.

When at full work, the vacuum in each vessel is as follows:—

	First Vessel.	Second Vessel.	Third Vessel.
Vacuum in inches of mercury .	3 to 5	12 to 15	18 to 21
Corresponding temperatures of boiling . . .	97° to 95° C. 207° to 203° F.	85° to 80° C. 185° to 176° F.	74° to 66° C. 165° to 151° F
Difference of temperature between the steam or vapour and the boiling liquid . .	10° to 12° C. 18° to 22° F.	12° to 15° C. 22° to 27° F.	11° to 14° C. 20° to 25° F
Total difference between the steam entering the first vessel and the boiling vapour leaving the third	——	——	107–70 = 37° C. 225–158 = 67° F.

These vacuums are kept up by the rapid condensation of the vapour, and their degree depends only on the ratio between the speed of condensation and the production of vapour. In consequence of the differences in vacuum within the three vessels there results a difference in pressure, the highest internal pressure corresponding with the lowest vacuum. Hence under these pressures, and without any other operation than the opening of the valves, the juice from the first vessel passes into the second, and the juice from the second into the third, through pipes C communicating from the bottom of each vessel to the space above the tubes in the next. Thus there is in ordinary working a continuous circulation of the juice, provided the valves in the pipes between the vessels are properly regulated. From the bottom of the third vessel is drawn off at D the concentrated syrup at 25° Baumé.

The efficiency depends first on the heating surface, secondly on the total difference of temperature between the boiling liquid and the steam. The larger the heating surface, and the greater the difference of temperature, the larger is the quantity of heat given up by the steam and absorbed by the juice. Thus, to attain from a given plant a higher efficiency, without altering the heating surface, it is sufficient to raise the temperature of the steam at its entry, or to diminish the

temperature of ebullition in the last vessel by employing a larger quantity of condensing water.

The evaporative power of this plant is from 22 to 25 kilog. of water per square metre per hour (4·51 to 5·12 lbs. per sq. ft.); or 6·5 to 7·5 hectolitres of juice per square metre per 24 hours (2·13 to 2·46 cub. ft. per sq. ft.). If we take the heating surface in the first vessel as unity, that in the second should be 1·25 to 1·50, and that in the third 1·50 to 1·75. For working 100 to 120 tons of beetroot per 24 hours, provision should be made for evaporating 1250 hectolitres of juice (4400 cub. ft.) in the same time.

The advantages of the triple-action evaporators are as follows:—(1) the quantity of condensing water may be reduced, in consequence of the repeated use of the steam and vapour; (2) the working is continuous and rapid; (3) the products are withdrawn from the injurious influence of the air; (4) the juice is enabled to boil at temperatures so much the lower as the richness in sugar is greater; (5) they are very economical in fuel, because the evaporation goes on in a vacuum.

BOILING.

This operation has for its object the concentration of the syrup, now at 25° Baumé, and its transformation into a "masse cuite" or Boiled Mass.

The boiling apparatus or vacuum pan, Fig. 22, Plate 36, is composed of three parts; first, a hemispherical bottom B of cast-iron, provided at its centre with a circular hole H for emptying, which is closed by a sliding door; secondly, the middle part, composed of a cylinder C provided with glass windows G, so that the boiling may be observed inside; thirdly, the upper part D, formed of a dome-shaped cover, which communicates by a large pipe P with a cold-water injection condenser J. The water injected, the vapour condensed, and the air are withdrawn as in the triple-action evaporators by an air-pump. Between the condenser and the dome is a catch-chamber K, intended to retain the froth, the syrup, and the crystals themselves, which are sometimes carried over by too violent ebullition.

The apparatus is heated by steam at high pressure, generally

$4\frac{1}{2}$ to 5 atmospheres. This steam circulates in three or four worms W inside the boiler, placed one above the other, from 0·30 to 0·40 metre apart (12 to 16 in.), and of dimensions proportionate to the capacity of the plant.

As in the triple-action evaporators, the boiling goes on in a vacuum; the degree adopted in practice varies from 17 to 24 inches of mercury, according to the stage of the operation. The corresponding temperatures of ebullition are 76° and 55° Cent. (169° and 131° F.) To regulate the vacuum, the man in charge has only to manage the steam cock on the one hand, and the cock for the cold-water injection into the condenser on the other.

The efficiency of this plant varies, first with the difference of temperature between the syrup to be boiled and the heating steam; secondly, with the heating surface of the worms. The temperature of the steam at 5 atmospheres is 152° Cent. = 306° F.; the mean temperature of the syrup when boiling, corresponding to a vacuum of from 17 to 24 inches, is 60° Cent. = 140° F.; the difference is thus 92° Cent. = 166° F. With a pressure thus diminished and with so great a total difference between the temperature of the juice and that of the steam, it is easy to conceive how rapidly the evaporation goes on. It attains the figure of 60 to 75 kilog. of water per square metre of heating surface per hour (12 to 15 lbs. per sq. ft.), or 1·50 to 1·65 hectolitres of syrup (5·30 to 5·83 cub. ft.).

The boiling process may be divided into four stages:—(1) evaporation of the syrup up to the crystallising point; (2) formation of crystals; (3) accretion of crystals; (4) final drying or compression.

(1) The crystallisation is obtained by the evaporation, up to the "string test," of a volume of juice representing about two-fifths that of the crystals left. The string test consists in simply placing a drop of liquid between the thumb and forefinger, which are then separated more or less. The test is reached when wide separation of the fingers gives a delicate thread which breaks, and of which the upper end presents at its lower extremity a small hook neatly formed. There are what are called light hooks and strong hooks; the latter correspond to more intense concentration, and are employed in the

crystallisation of impure and viscous sugar. This latter test corresponds practically to a density of 42½ to 43° Baumé.

(2) The formation of the crystals is due to the state of super-saturation in which the syrup exists at the crystallising point. It is indicated by the formation of an immense number of small grains of sugar. This is the moment when the foreman has to attend to the formation of crystals regular in shape, sufficiently large, hard, and well formed. This is achieved by pumping in additional charges of syrup in amounts exactly equal to each other, and at intervals more or less long.

(3) The accretion of the crystals once formed is produced by a continuous pumping in of syrup, so as to maintain the mass in a proper state of fluidity. As it evaporates, this syrup gives up its sugar, which settles upon the crystals already formed and increases their size, according to the laws of crystallisation. The introduction of the syrup should be carefully watched. If the quantity is too great, the crystals are re-dissolved; if it is too small, the mass returns rapidly to the state of super-saturation, small crystals are formed afresh, and the final product is irregular. Small or large crystals may be produced at will, following the principle that slow crystallisation gives large and regular crystals, and rapid crystallisation gives small and irregular crystals. The grains will be large if the boiling goes on slowly, if large charges of syrup are added at long intervals, and if the syrup is diluted. They will be small on the contrary if the boiling is rapid, if the additions of syrup are frequent and small, and if the syrup is concentrated.

(4) The crystals are dried to the degree required by ceasing to supply the syrup, and introducing only a thin current of steam. The point at which to stop is of great importance. If you stop too soon, many crystals will remain dissolved in the syrup and the yield will suffer accordingly; if you stop too late, the crystals are found glued in a mass, and difficult to separate. The degree of drying varies with the purity of the product; the more impure, the less it should be dried. When the crystallisation is over, the valve at the bottom of the pan is opened, and the contents drawn out into vats called coolers or crystallisers, which are maintained as near as possible at a temperature of 20° to 25° Cent. (68° to 77° F.).

The duration of the process is from eight to ten hours. The quantity of crystals obtained per 1000 kilog. of beet-root depends first on the quality of the beet-root; secondly, on its state of preservation; thirdly, on the degree to which the crystals are dried; fourthly, on the perfection of the process. Generally the volume varies from 0·600 to 0·675 hectolitre per 1000 kilog. of beet-root (2·12 to 2·38 cub. ft. per ton); the weight of a hectolitre is 138 to 142 kilog. (86 to 89 lbs. per cub. ft.). The yield of No. 1 sugar is from 85 to 95 kilog. to the hectolitre of No. 1 crystals (53 to 59 lbs. per cub. ft.).

Centrifugal Separation.

The object of this process is to separate the grains of sugar from the syrup which contains them, the mixture forming what we have called the "boiled mass." It is performed by means of centrifugal machines, in which a vertical shaft, running in a fixed bearing at the top and on a pivot at the bottom, carries a drum 0·75 metre in diameter and 0·30 metre in height (30 in. and 12 in.); the circumference of the drum is lined inside with a cloth, or a sheet of iron pierced with holes sufficiently small to retain all the little crystals of sugar. In general the shaft receives its motion from the top by friction cones, and has a speed of 1,000 to 1,200 revolutions per minute; in exceptional cases the motion is given from below. Under the action of the centrifugal force the boiled mass is spread out upon the cloth or perforated plate, and the syrup passes out through the holes, whilst the grains of sugar remain behind, forming a layer which can be purified by simple rotation, until a sugar is obtained of any desired richness and quality. Sometimes however clarification by means of water or steam is employed. By this means a sugar is obtained, the grains of which are perfectly white and dry, and of great richness. This sugar may be sold at once, and may even compete with refined sugar. Two machines are enough to work 80,000 or 100,000 kilog. (80 to 100 tons) of beet-root in the twenty-four hours; in each operation from 30 to 40 kilog. of boiled mass (66 to 88 lbs.) are charged into each machine, and produce 25 to 35 kilog. of sugar (55 to 77 lbs.). Each operation lasts eight to ten minutes.

From the boiled mass No. 1 we thus obtain by the centrifugal process a sugar also called No. 1, and a first waste syrup.

This syrup is boiled over again under a vacuum of 18 to 22 inches, is concentrated to the crystalline point by the test of the strong hook, and crystallised in vats of from 60 to 70 hectolitres (210 to 250 cub. ft.), placed in chambers kept at a temperature of 30° to 35° Cent. (86° to 95° F.). These hot chambers are called "*emplis*." The mass thus obtained is called boiled mass No. 2. It must be remarked that no formation of grains takes place in the boiling in this process: the syrup is not sufficiently pure. The crystallisation takes place in the hot chamber, after a time which is longer as the crystalline mass is more impure, and generally is about four weeks. At the end of this time the centrifugal process is carried out, and a sugar is obtained called No. 2, together with a second waste syrup. This sugar No. 2 is browner and more impure than No. 1. The second waste syrup is again boiled, concentrated under the same degree of vacuum and to the same test point as the first, and crystallised in "*emplis*" heated to from 40° to 45° Cent. (104° to 113° F.).

In consequence of the growing impurity of the product, the slowness of the crystallisation increases, and whilst four weeks are sufficient to crystallise the mass No. 2, five to six months are required to finish the process in the mass No. 3. Then by the centrifugal action a sugar called No. 3 is obtained, yet browner and more impure than No. 2; and also a third waste syrup which is called Molasses.

This molasses forms a final residue in the make of sugar; it is a product which despite its richness in saccharine matter, amounting to 40 or 50 per cent. in weight, cannot give crystallised sugar by fresh boiling. In Belgium it is sold to Belgian or foreign distillers to make alcohol. Its commercial value is from 9 to 15 francs per 100 kilogrammes at 42° Baumé. The proportion of molasses varies from 2·5 to 3·5 per cent. of the weight of the beet-root.

Many processes have been proposed to extract sugar from molasses. That of osmosis is the only one applied in Belgium, and only by about half the works. The cause which prevents its becoming general is simply the supplemental duty of 6 per cent. on the total make of the season, which is exacted by the Excise.

OSMOSIS OF MOLASSES.

This process consists in applying the principles of endosmosis and exosmosis to molasses. The liquids to be treated consist of water on the one side and molasses on the other, separated by a sheet of parchment paper. A current of endosmosis takes place from the water towards the molasses, and a current of exosmosis in the opposite direction. The object of osmosis is to carry off the salts diffused through the mass. In particular it takes off the greater part of the salts of potassium and sodium, and thus restores a certain quantity of sugar which these substances had rendered non-separable.

The Osmogene, or apparatus used, Figs. 24 and 25, Plate 38, is composed of a series of 51 wooden cases, Figs. 26 and 27, about 1·15 metre long, 1·00 metre wide, and 0·66 metre high (46 in. × 40 in. × 26 in.), the wood being 15 millimetres thick (0·6 in.). There are different types of construction. They are placed next to one another, side by side, with a sheet of parchment paper between each, and the whole bolted tightly together: thus there are formed a series of chambers filled alternately with molasses and water. In the compartments of the even numbers, Fig. 25, there is an ascending current of molasses heated to 60° to 75° C. (140° to 167° F.), and in the compartments of the odd numbers a descending current of water at 75° to 80° C. (167° to 176° F.). The analysis by osmosis takes place through the membranes; part of the water enters into the molasses, and part of the salts of potassium and sodium passes into the water, as well as a certain quantity of sugar, which is also soluble in the water. The water thus charged with salts and sugar is called water of exosmosis.

The effect of osmosis will be greater as the molasses leave the osmogene in a more diluted condition, in consequence of a more prolonged contact with the water, and of a larger volume of water having passed through in proportion to the quantity of molasses. The molasses may leave at 20°, 18°, 15° or even 12° Baumé. The effect of osmosis is measured by the increase in the saline coefficient of the molasses which has been treated, compared with that which has still to be treated. The higher this coefficient has been raised, the greater will have been the improvement and the larger the quantity of sugar recovered. The saline coefficient is found by dividing the percentage of sugar by the percentage of ash. To

be satisfactory the increase ought to be at least 2, but with the condition that the saline coefficient in the water of exosmosis does not exceed 1, that is to say that in this water the content of sugar and of salt should never pass the ratio of 1 of sugar to 1 of salt.

In an osmogene about six times more water passes than molasses, and each apparatus will produce 7 to 8 hectolitres of boiled mass per 24 hours (25 to 28 cub. ft.).

According to the nature of the molasses, the employment of osmosis allows the formation of boiled masses numbered 4, 5, 6, and even 7, the osmosis of course being performed afresh after each. A time however will come when the concentration of the organic matter and of other matters incapable of diffusion is so great that the point of crystallisation cannot be attained, and then all further crystallisation becomes impossible.

It is estimated that 1 kilogramme of saline matter expelled will restore 3·5 kilog. of sugar. The loss in osmosis varies from 15 to 20 per cent. of the weight of the molasses treated, and the yield of sugar varies from 20 to 25 kilog. per hectolitre of boiled mass produced (12½ to 15½ lbs. per cub. ft.). The employment of the process will depend upon the proportion existing between the value of sugar and that of molasses.

Osmosis, if well managed, will eliminate as much as 50 per cent. of the saline matter; and this, assuming a coefficient of 3·5, would give, for a molasses containing 13·17 per cent. of ash, 23 per cent. of sugar regenerated, supposing that this could all be separated by a single crystallisation. In general 100 kilog. of molasses, after thorough osmosis from 43° to 13° Baumé, will give 20 kilog. of sugar with a loss of 50 kilog. in molasses; and 50 kilog. of molasses in a normal condition will remain. Some works have begun to concentrate their water of exosmosis to 42° Baumé, and then sell it. This may be considered as the first step towards "osmosis à outrance," as already used to some extent in France. This comprises simple osmosis, concentration of the water of exosmosis, crystallisation of the salts, and re-osmosis of the new molasses thus obtained. The yield in salts thus recovered to agriculture (a mixture of nitrates and alkaline chlorides) may reach 3 per cent. of the amount of molasses first subjected to osmosis.

Table of Analyses showing the Composition of the Juice and of its Products in the different Stages of the Manufacture.

	Density.	Sugar per cent. In volume of juice.	Sugar per cent. In weight of juice.	Sugar per cent. In weight of beet-root.	Quotient of purity.	Standard of value.	Alkaline matter.
	Baumé.	per cent.	per cent.	per cent.			grammes.
Beetroot (mean of 1500 analyses)	1·0537	11·49	10·90	10·35	82·70	9·02	
Juice not limed	1·0400	8·51	8·18	...	81·80	...	
Juice limed	1·0456	7·65	7·32	...	64·98	...	0·91 (% of juice by volume)
Juice of the first carbonatation	1·0331	7·39	7·16	...	87·04	...	0·1180 (% of juice by volume)
Juice of the second carbonatation	1·0323	7·38	7·15	...	88·60	...	0·0280 (% of juice by volume)
Juice filtered through animal charcoal	1·0311	7·25	7·03	...	89·73	...	0·0240 (% of juice by volume)
Syrup before filtration	1·2105	48·91	40·34	...	87·02	...	0·1040 (% of juice by volume)
Syrup after filtration	1·2005	46·09	38·40	...	87·32	...	0·0930 (% of juice by volume)

	Density.	Crystallisable.	Ash.	Water.	Organic matter.	Quotient of purity.	Yield of boiled mass per 1000 kilos of beet-root.	Yield of sugar per hectolitre of boiled mass.	Ordinary limits of yield per hectolitre according to the quality of beet-root.
	Baumé.	per cent.	per cent.	per cent.	per cent.		hectolitres.	kilos.	kilos.
Boiled mass No. 1	—	82·22	5·14	6·43	6·21	87·87	0·59	88·60	86 to 91·75
Boiled mass No. 2	—	66·32	10·35	12·64	10·69	76·00	0·26	44·10	40 to 52·00
Boiled mass No. 3	—	58·45	13·65	13·08	14·82	67·25	0·17	15·42	15 to 30·00
Molasses	42·10	46·34	13·14	20·40	20·12	58·22	26 kilos		

	Crystallisable.	Ash.	Water.	Organic matter.	Standard of value.	Yield per 100 kilos of beet-root.	Ordinary limits of yield per 100 kilos of beet-root according to the quality of the beet-root.
	per cent.	per cent.	per cent.	per cent.		kilos.	kilos.
Sugar No. 1	96·01	1·22	1·525	1·245	89·91	5·227	5 to 6
Sugar No. 2	91·04	3·00	3·06	2·90	76·04	1·146	0·90 to 1·35
Sugar No. 3	90·87	3·13	3·05	2·95	75·22	0·262	0·20 to 0·35
						6·635	6·10 to 7·70

ANALYSES OF BY-PRODUCTS.

Pulp from the hydraulic press.

Moisture	from 70 to 75	% by weight.
Sugar	from 5·50 to 7·50	% by weight.
Quotient of purity in the juice	72	

Pressed Pulp from the diffusion process.

Moisture	from 88 to 90	% of weight of pulp.

Unpressed Pulp from the diffusion process, representing about 70 per cent. of the weight of the beet-root.

Sugar	from 0·43 to 0·85	% of weight of pulp.
Water contained	from 0·15 to 0·25	% of weight of beet-root.

Scum from the first pressing.

Sugar	from 3 to 4·5 %

Scum from the second pressing.

Sugar	from 1·50 to 1·80 %
Moisture	from 41·50 to 43·50 %

Juice from the second pressing.

Sugar per cent. in volume	3·00
Quotient of purity	79·00

Fermented Scum for manure.

Moisture		36·100
Solid Matter	Nitrogen	0·347
	Phosphoric acid	0·914
	Potash	0·153
	Lime	30·065
	Organic matter non-nitrogenous	30·919
	Matter not examined	1·502
Total		100·000

Waste from animal charcoal.

In dust	Water	3·14 %
	Phosphoric acid in a state of tri-calcic phosphate	33·38 %
Mud deposited	Water	20·74 %
	Phosphoric acid in a state of tri-calcic phosphate	21·68 %

ANALYSIS OF OSMOSIS.

	Density Baumé.	Crystallisable Sugar.	Ash.	Saline Coefficient.
Molasses before osmosis	42·14	44·08	11·02	4·00
Molasses after osmosis	17·00	21·17	3·33	6·35

This shows an improvement in saline coefficient to the extent of 2·35. The water of exosmosis shows crystallisable sugar 0·75, ash 0·76; or one of sugar to one of ash.

Mode of Valuing Sugar.

Sugar is sold according to its richness. To obtain the figure of value which regulates the sale, the figure for ash is multiplied by 5, the figure for uncrystallisable sugar is added, and the total of the saccharimeter figure is subtracted. In selling raw native sugar, four kinds are distinguished; (1) sugars taken on a basis of 88°, in which the figure of value is 85° minimum and 92° maximum, inclusive; (2) sugars taken on a basis of 85°, in which the figure of value is 82° minimum and 86° maximum, inclusive; (3) sugars taken on a basis of 75°, in which the figure of value is 70° minimum and 82° maximum, inclusive; (4) sugars taken on a basis below 72°.

The degrees and fractions of degrees above or below the basis of value are calculated as follows:—1·25 francs per degree for sugars of basis 88° and 85°; 0·30 franc per degree for the sugar of basis 75°. If it should be stipulated that the seller may deliver sugar above 92° or below 70°, each degree is calculated as follows:—Above 92° at 1 franc; below 70° at 0·90 franc.

Sugars may be sold either for exportation or for home use. On exported sugar a drawback is allowed by the Excise, which is fixed as follows:—For native raw sugar not moistened, 45 francs per 100 kilog. for No. 11 and above (this is the first class, on which the whole of the duty is returned); and 40·91 francs per 100 kilog. for sugars No. 8 to No. 11 exclusive (this is the second class, on which only a partial return is given). The numbers 11 and 8 indicate merely varieties of shade, the colour corresponding to types which are designated by these numbers.

The quantity exported, and on which the drawback is paid, cannot in any case exceed the quantity taken by the Excise. Any excess over the quantity so taken must then be sold for home consumption; but in the latter case the amount of the tax is still added to the selling price of the goods. Thus the buyer has to reimburse the manufacturer for a tax which he has not paid, so constituting a bounty to the latter.

A sugar on which the drawback is payable, that is to say, which comes within the limits of the Excise, may equally be sold for home

consumption. In this case the manufacturer is still reimbursed by the buyer for the taxes which are comprised in the selling price, but he remains debtor for these taxes to the State.

The customs charged on raw sugar from abroad correspond to the drawback on the native sugar exported of the same class, as follows:—

		Fr. per 100 kilog.
Foreign raw sugar	below No. 7	34·26
	from No. 7 to No. 10 exclusive	40·91
	from No. 10 to No. 15 „	45·00
	from No. 15 to No. 18 „	48·07

The paper may be terminated by some statistics on the subject.

		Hectares.		Acres.
The area under cultivation for beet-root	In 1846 was	2,121	=	5,241.
	In 1866 „	18,000	=	44,480.
	In 1882 „	35,000	=	86,490.

The last figure is calculated on the assumption of a return of 40,000 kilog. per hectare (16 tons per acre), and an excise of 5·75 kilog. per 100 kilog. of beet-root.

The sugar works which were in action during the season of 1882–3 were as follows:— 98 with hydraulic presses, 2 with continuous presses, 42 with the diffusion process; and 1 work with separate rasping mills, having 9 rasping mills with hydraulic presses and 4 with the diffusion process.

The Excise quantity of raw sugar for the season 1882–3 was 80,408,809 kilog. (80,400 tons). Of this 6,483,466 kilog. (6,480 tons) belong to the central works.

The statistics of raw sugar are as follows:—

	1880–81. Kilog.	1881–82. Kilog.	1882–83. Kilog.
Total make	68,626,000	73,136,000	80,000,000 (probable)
Total exported	——	63,833,000	——
Total imported	——	22,289,614	——

The statistics for refined sugar are as follows:—In 1881–82 the quantity exported was 11,475,874 kilog., and the quantity imported 5,629,727 kilog. The average consumption during the three seasons 1879–80, 1880–81, 1881–82, was 21,223,909 kilog.: the population

being 5,600,000, this gives 3·79 kilog. per head (8·34 lbs.). This figure would reach about 5·25 kilog. per head (11·55 lbs.), if account were taken of the various products which escape the notice of the excise, but which all go into consumption.

ON THE APPLICATION OF ELECTRICITY TO THE WORKING OF COAL MINES.

By Mr. ALAN C. BAGOT, of London.

The writer proposes to divide this subject into two heads, as follows:—

(I.) The application of electricity to signalling purposes.

(II.) The more recent application of powerful electric currents for the purpose of illumination, or of transmission or storage of power, both on the surface and within the workings of the mine itself.

I. Electric Signalling in Mines.

The increased depth of the shafts of collieries in this country, and the introduction of rapid winding gear, have rendered the method of mechanical signalling, known as the "hammer and plate" system, quite obsolete. By this system the only signals that could be exchanged between the cager, or man at the bottom of the shaft employed in loading tubs on the cage, and the banksman, or man in charge of the surface and engine room, were produced by pulling a wire attached to a hammer, which knocked its signals on a piece of boiler iron. This caused great loss of time and unnecessary labour, as well as some danger, on account of the lapse of time between each signal. Again, the wire frequently broke, causing risk to those employed in getting the broken part out of the shaft, and very serious delay when the pit was drawing coal. The result of such a break is to fill the road going "out bye," or to the pit bottom, with loaded tubs that cannot be drawn up till the signals are repaired. Consequently no empty tubs are available, to be taken in to the working faces where the men are getting coal. The loss

of time thus caused is very much greater than would be supposed at first sight.

The writer's experience further shows that, in cases of accident traced to defective signalling, contradictory explanations were generally offered by those in charge of the signalling appliances. Again, in the case of inclined planes underground, driven by an engine on the surface, unless the latter can be signalled to stop *instantly* from any part of the road, fatal accidents will be of such frequent occurrence as to render any extensive scheme for such haulage a matter of grave responsibility to the manager, and of great and unnecessary risk to the men. A further source of danger was present in foggy weather, when the engine-driver had nothing to guide him but the shaft distance-indicator, required by the Mines Regulation Act; nor could he at any time tell the position of the "kips" or bolts upon which the cages rest when at the top of the shaft, or know when they were pulled back to allow him to lower the cage down the pit.

In 1874 the writer determined on using electricity for signalling purposes; and from thence to 1877 he carried on a series of experiments in different shafts with a view to determine whether insulated cables, naked copper wire, stranded copper or iron wire, or galvanised-iron telegraph-wire, was the most suitable conductor for conveying the current in the shafts. The result of trials in several different districts showed that insulated cables were too expensive in the first instance, and also were practically useless, being stripped and destroyed by falling coal from the cages, &c., and especially liable to electrical leakage. What was still worse, they were subject to a form of back charge, due no doubt to the coating of coal-dust which adhered to the sheath of the cable. Further, their position did not allow of their being readily tested or inspected; and unnecessary delay took place in finding disconnections and other electrical faults, when the cable was not manifestly disturbed or injured. Stranded iron wire was found too prone to rust, and of too high an electrical resistance; stranded copper wire too heavy; solid copper wire too soft and apt to draw out. No. 11 galvanised-iron telegraph-wire (0·120 in.) was too light, and of too

high a resistance for either shafts or engine planes. Finally No. 4 (0·238 in.) galvanised-iron telegraph-wire was found most suited for shaft conductors, and No. 8 (0·165 in.) for engine planes.

The shaft conductors were hung vertically from shackles on the pit-frame to the bottom of the shaft, without any intermediate support, the depth in some cases being 600 to 700 yards. The conductors were provided with wooden blocks on each side of the wire, screwed tightly together with thumb-screws, to act as safety clips, and to prevent the wire from falling down the shaft in the event of an overwind or explosion carrying away the shackles on the pit-frame. To the lower end of each wire, which hung free in the sump, was attached a 20-lb. weight to act as a compensator. Harris's Deep Navigation Colliery at Quaker's Yard was thus fitted in 1880, the depth of the south pit to the 4-ft. Aberdare seam being 695 yards.

The arrangement of No. 8 wire for the engine-plane signals at Risca, North Dunraven, and other collieries, was practically the same as an ordinary overhead-telegraph line, the special support found most suitable being a brown stone-ware insulator, Figs. 1 and 2, Plate 39. For a single road the insulators are spiked at suitable distances into the props on one side of the road, and for a double road into the overhead collars or cross-timbers. The line wire passes over the groove of the insulator, and is prevented from running back in the event of a break by a binding wire passing round the insulator, as shown in Fig. 2; the binding wire used for this purpose is No. 16 charcoal-iron wire (0·065 in.), which is bound and soldered securely round the line wire.

The insulated copper connecting-wires, such as battery and instrument wires, were made of No. 16 B. W. G. copper wire (0·065 in.), which was insulated with a covering of gutta-percha, making it equal to No. 7 B. W. G. (0·180 in.), then wound with tape, and tarred with Stockholm tar.

The batteries found most suitable were twelve-cell large-size Leclanché batteries; the outsides and the insides of the glass cells down to the level of the exciting fluid were well brushed with paraffin oil to prevent efflorescence and evaporation. The evil effect of coal-dust in the pit batteries was avoided by pouring a little

common engine-oil on the surface of the exciting fluid, thus sealing it from the air of the mine. Much advantage was derived in wet shafts, where the electric leakage was great, by duplicating the pit batteries for quantity, and thus keeping the tension low. The electrical connections for such an arrangement are as shown in Fig. 3, Plate 39. It is frequently assumed that the greater the battery power the stronger the signals. This is not the case where insulation is defective; the remedy lies in coupling up more cells for quantity and keeping the tension low.

The system employed at Cannock and Rugeley Collieries, Fig. 4, Plate 39, consisted of a single-stroke bell-circuit, ringing from pit to bank and engine simultaneously, and from bank to pit only, on 9-inch electric gongs of special construction; also a 12-order dial-circuit from pit to bank and engine, and again from bank through the engine dial to the pit dial. When winding coal, the banksman, using the bell circuit only, rang twice to the cager as soon as he had taken off the full tub and put an empty one on the cage. The cager, having received this signal that the banksman had completed his operations, and having also himself taken off the empty tub and put on a full one at the pit bottom, signalled twice to bank and engine simultaneously, thus warning the banksman that he had signalled the engine-driver to start. In practice this has been found far safer and quicker than the prevailing custom of the banksman starting the engine-driver. For the purpose of signalling the driver to stop, the banksman was provided with a local bell-circuit from bank to engine only; but in all cases, except when the sinkers were in the pit, the starting signal was taken from the cager only.

The electrical transmission of special orders is effected by the two dial-circuits previously mentioned; the current being supplied from the batteries required for the bell service. The transmitters are simply circuit closers, provided with mechanical means for ensuring an electrical contact of given duration; and by means of an air-piston, provision is made that the apparatus cannot be left in such a position that the circuit remains closed. The order transmitted to the receiver is also shown on the dial of the transmitter's instrument, and he only can alter it. The receiver is unable to alter either his

own dial, or that of the sender. This secures an absolute block system. The receiving instruments are provided with a peculiar check escapement to impel the ratchet-wheel on the passage of the current; and the balanced action of the armature of the receiving electro-magnet locks the indicating needle in the proper position. The same arrangement is applied to the indicating dial of the transmitting instrument. In practice twelve separate orders may be transmitted in ten seconds.

Latterly however, in the present year, with a view to leaving the banksman and cager at liberty, it has been found desirable to substitute clockwork transmitters in place of the step-by-step transmitters. In these new instruments the natural operation would be for the clockwork to run itself down. This is prevented by a revolving projecting pin coming in contact with the pin of a lever corresponding to the zero point on the signal, and denoting "safety." On pushing back this No. 0 lever, and pulling out No. 5 lever, the clockwork revolves, makes five separate contacts, transmits five electric currents of given duration, and actuates the receiving apparatus five times; the corresponding order, namely "men coming up," being simultaneously indicated on all the dials in the circuit. The revolving projecting pin of No. 5 lever then arrests the clockwork until the transmission of the next signal, before which No. 5 lever must be pushed back. The receiving dial in the engine-room thus informs the engine-driver of what is passing; and if No. 1 cage is drawing men up and No. 2 cage is sending timber or loaded trucks down, contrary to the provisions of the Mines Regulation Act, he will not start his engines. The repetition by the receiver of the sender's order of "men coming up" (or going down, as the case may be) constitutes an absolute block, and informs the engine-driver of what he is winding in the up cage; it also prevents mistakes between the banksman and cager, through which many fatal accidents have occurred previous to the introduction of this system. Fig. 4, Plate 39, shows the general arrangement of lines and instruments for shaft signals, as in operation at the Risca, Harris's Navigation, and Cannock and Rugeley Collieries.

Provision is further made, if necessary, for electrically interlocking

the kips with a semaphore in the engine-room; so that when the kips are withdrawn by the banksman, to allow of the free passage of the cage, the arm of the semaphore is moved from "on" to "off" by the action of an electric current automatically transmitted from the banksman's battery at the moment of pulling the lever over. This semaphore thus indicates automatically to the driver in foggy weather the operations of the banksman.

In engine-plane signals, the bell signals are made at any part of the road, by simply making connection between the line and the return wire, and thus closing the circuit; this can be done by the boy in charge of the journey, while the tubs are running. Narrow or dangerous inclines, where power is used to work the trains, are a fruitful source of accident. Men using the inclines as travelling roads, and thus meeting the tubs coming out, are crushed against the sides of the road. Under certain circumstances the writer has found it advantageous to protect the roads by means of electrical train-indicators. The indicating instruments, used at each end of the block section of the road thus protected, are constructed as follows. An electro-magnet M, Fig. 5, Plate 40, is provided with an armature K, balanced on a pivot, at the end of which is a semaphore arm A. The armature and the signal being about equally balanced, when a current flows through the electro-magnet M, the armature K is attracted, and the semaphore arm A flies up to "danger." To show "line clear" or safety, when required, the operator presses down the lever E, which mechanically throws the signal to a position of safety. The keys used for transmitting the current are what are technically called "Morse keys," and are fitted underneath the semaphore signals, as shown in the side and end views, Figs. 6 and 7.

When in use in coal mines, the apparatus is fitted up as shown in Fig. 8, Plate 39. Supposing A and B represent the two ends of the incline or plane, it will be seen that a man can enter the section at B, the semaphore indicating "line clear"; but when in charge of trucks or tubs he should in doing so throw the signal at A to "danger," and then no one should start from A to B. Where compressed-air locomotives are in use, this system is almost essential to the safety of the men, if the road is used as a travelling road. Some of the worst

accidents the writer has had experience of have originated in using engine planes as travelling roads without proper means of ascertaining whether it is safe to enter; and he submits that no power should be used for haulage underground unless electric signals are used and the planes properly protected.

Another application of electricity in coal mines is the Electric Recording Anemometer introduced by the writer. The hemispherical rotating cups are placed in the main return air-way, and the recording apparatus in the fan engine-room at the surface. This apparatus consists of suitable clockwork to pay out a given length of paper tape in a given time. Every five minutes the clock closes a local electric circuit within the apparatus, and thus the time is punched on the tape. The revolving cups in the return air-way are geared into a revolving wheel, so insulated that it makes contact once in so many revolutions. This apparatus and the recorder are connected together with No. 11 galvanised-iron telegraph-wire (0·120 in.). According to the variations in speed of the air in the mine, the number of these closings of the circuit will vary; and, by means of a similar punching apparatus to that of the local circuit, each contact is registered on the tape by a dash similar to that of a Morse printing instrument. The number of dashes in each five minutes' interval shows the mean speed of the air, together with its variations; the tape forming thus an automatic and continuous record of the speed of the main air-current, taken at any desired part of the mine.

There is another application of electricity which has been found extremely useful by the writer. It is desirable at times to hear the action of pump-valves in the pit, without having to send the sinkers down. For this purpose the writer has used with success a modified telephone, attaching it to the outside of the valve cover; but to get really exact repetitions of the beat of the valves, a stout piece of asbestos card should be interposed between the valve cover and the mouth of the telephone. A little practice enables the engine-man to follow the action of the valves as accurately as when, in the human body, the heart's action is examined by means of the stethoscope.

II. Application of Electricity in Mining, for Illumination and for Transmission or Storage of Power.

In 1881 the writer experimented at length on the illumination of the pit-bank and screens at Harris's Navigation Collieries. A Gramme dynamo machine was driven off an engine that worked a Schiele fan, thus ensuring great steadiness of motion and economy in motive power. The result of the experiment showed that incandescent lamps were useless, and powerful arc lamps, fixed 40 ft. above the ground, the most suited for the purpose. On account of the absence of colour in the light, the coal trimmers could pick off "brass" and "pyrites" quicker by the arc lamps than by incandescent lights. In every way the experiments proved conclusively that electric illumination of the surface was desirable at a mine of any great magnitude, and that the ordinary engineering staff of a colliery was capable of maintaining the appliances in operation after a week's instruction; but it was generally agreed that the introduction of alternating high-tension current machines was very unadvisable, on account of the likelihood of accident to the men. It was observed by the writer that no amount of warning to the colliers would induce them to leave the line wires alone. Of all types of dynamo machines, the Edison low-tension machine is most suited, in the writer's opinion, for colliery purposes; while the Brockie, Serrin, or Crompton arc-lamps are suitable, if an arc is required for illumination, in connection with a Gramme or Siemens dynamo.

At the Risca Collieries the electric light is introduced into the pit from a dynamo machine driven at the surface. The cable is taken down the shaft, and connected with a series of Crompton incandescent lamps of large size at the bottom. These give an excellent light, and facilitate very greatly the work of the cagers and the men in the gate-roads. But as regards the introduction of such lights into coal mines, for the purpose of illuminating the working stalls and faces, the writer wishes to draw attention to the 7th general rule, section 76, Mines Regulation Act, 1872, which provides that "In every working approaching any place where there is likely to be an accumulation of explosive gas, no light or lamp other than a

locked safety-lamp shall be allowed or used." It must be borne in mind that with safety-lamps a constant watch is kept on the appearance of gas. Now a blower of gas has been known by the writer to back up against an air current of 65,000 cubic ft. per minute passing down the split; and with electric lamps no notice would be given of the fact. Such accidents—or again, a fall of roof breaking a wire, or the breakage of a lamp—cannot be guarded against; and hence the writer is of opinion that no increased safety would be afforded by the electric illumination of the working faces from dynamo machines. The danger of breaking line-wires may indeed be avoided by the use of accumulators or secondary batteries, charged at the surface from a dynamo machine. But it is stated that thirty Faure accumulators, weighing in all about 2 tons, were required to illuminate, by means of incandescent lamps, the Pullman express on the London Brighton and South Coast Railway between Brighton and London. Hence the applicability of such batteries in their present state to coal mines seems very doubtful. It must be borne in mind that a miner, when holing, requires his safety-lamp just above or below his work, and is constantly shifting its position and his own, as the holing progresses, to set sprags. This would be a serious difficulty; and further, before withdrawing his sprags to allow the coal to come down, he would have to move the incandescent lamp away altogether and refix it afterwards. Allowing ten minutes for the two operations, this in a mine of sixty working stalls would entail a loss of ten hours per day, say one man's labour, or 3*s.* 6*d.* daily. Except in long-wall work, reflected illumination by means of electricity would be impracticable. In effect therefore, without going into details of cost at the present time, electricity can only be successfully applied to the illumination of the working faces by means of a hermetically sealed glass incandescent lamp, containing a supply of electricity for nine hours' consumption. If this is charged from dynamo machines at the surface, due regard must be had to the length of time occupied in the operation. The weight of each electric lamp should not exceed that of the present lamps in use, or 3 lbs. as a maximum. Such an appliance does not at present exist.

The useful application of electricity for the transmission of power would be confined to underground haulage, on the electrical tramway principle of Sir William Siemens and others. But, according to the writer's information, such engines as those constructed at the Grange Iron Works, Durham, or compressed-air locomotives, are capable of being used far more economically than electricity; so that the question of electric haulage need not be considered. In support of this statement the writer may state that compressed-air locomotives have been recently introduced into the Cannock and Rugeley Collieries with a result that may be regarded as eminently satisfactory. The load taken at each journey is 10 tons, the gradient being $1\frac{1}{2}$ in. per yd. or 1 in 24. The distance run is 220 yds., the total daily work 300 tons, and the speed 8 miles per hour. The cost for haulage is $\frac{3}{4}d.$ per ton. The air is first compressed to a pressure of 75 lbs. per sq. in., and ultimately to a pressure of 350 lbs. per sq. in. for use in the locomotive; and by having an excess of receiver-room all difficulties of latent heat are avoided. The cost of the locomotive was £250, and that of the compressor £70; and the engine does the work of three 14-hand horses. The cost of producing an equal amount of power by means of electricity would be more than twice that sum; and the electrical leakage in coal mines would be an almost insurmountable obstacle to its use.

Steam hauling-engines and compressed-air locomotives, with the tail-rope system in use at many collieries, have proved so satisfactory and economical, that the time has not yet arrived when electricity can be economically applied to take their place; whilst the transmission of power to fixed points in coal mines is undoubtedly best secured by means of compressed air, the exhaust of which is of such value for ventilating the workings.

Recapitulating the points mentioned, the writer advocates the use of electricity for the purposes of signalling and illumination, as regards the pit-bank and pit-bottom; but cannot at present approve its adoption for the transmission of power in the workings, or for illumination at the working faces. He is of opinion that no increased

safety would be derived therefrom, and that inconvenience and danger might arise through falls of roof; whilst the constant watch upon gas, kept by the present extensive use of self-extinguishing lamps, would be removed. Lastly, in the writer's opinion, the 7th general rule of the Mines Regulation Act, 1872, would not be complied with in such cases.

With regard to the use of electricity for signalling, the writer is convinced that the time has arrived when rapid-winding collieries should abandon their old hammer-and-plate system and adopt dials. Experience at the Risca Colliery showed that it was impossible to work a comprehensive system of underground haulage from the surface without electric signals. But it should be borne in mind that, unless electric signals are erected by competent men, they are far more dangerous than ordinary mechanical signals; and that where the electric signals are in use it is desirable to have at least one man instructed in a line-man's duties: this applies equally in the matter of electric-light machinery.

The writer has brought the subject before the Institution, after several years' experience, because he is impressed with the present inadequate signalling arrangements, and the increasing risks to which all classes of underground men are exposed by the introduction of rapid-winding machinery on engine-planes where mechanical signalling is used. On the other hand, the application of electricity for surface illumination is only a convenience and not a necessity; while for underground illumination the writer adheres to self-extinguishing safety-lamps.

Abstract of Discussion on Application of Electricity to the Working of Coal Mines.

M. TRESCA had read the paper with much interest, and was in complete agreement with it on almost all points, but he thought that the author had not attached sufficient importance to the use which could be made in mining of the electrical transmission of power to a distance, at least for temporary purposes. In all cases where it was necessary to transmit a certain amount of power, and where it was not possible to transmit that power by a single rope, hanging vertically in the shaft, electricity would be found a valuable agent, especially for rapid working. He desired to offer a sketch of the present state of this question in France. In the mines of La Perronière, near St. Etienne, power was conveyed by electrical transmission to a distance of 500 metres (550 yards); and experience showed that the useful effect was at most about 30 per cent. This question of useful effect, which was the key to the whole, had been minutely studied by himself and reported on to the Academy of Science in Paris.* To transmit power by electricity costly appliances were necessary. While the motor engine moved comparatively slow, the generator, or machine generating electricity, had to run at 1000 or 1100 revolutions per minute; and in rising, by means of gearing or otherwise, from the slow to the quick speed, much power was necessarily wasted. Again, at the other end, the receiver, or machine receiving the electricity from the cable, ran at a high speed, and this had to be slowed down to the moderate speed required in the shafts transmitting the mechanical work. There were thus several sources of loss of power between the motor engine and the main shaft, as follows: (1) loss in getting up the speed from that of the motor to that of the generator; (2) loss within the generator itself in the transformation of mechanical into electric energy; (3) loss in transmission along the cable, due to heat, leakage, &c.;

* See "Comptes Rendus," 1883, 19th and 26th February.

(4) loss within the receiver in transforming electric back into mechanical energy; (5) loss in slowing down the speed of the receiver to that of the main shaft. The question was, what were the influences of these various losses on the final result as to useful effect? On this there was now a considerable amount of evidence. In the experiments tried in France by M. Marcel Deprez, he was enabled to transmit 5 to 6 HP. to a distance of 17 kilom. (10·56 miles); but he himself had made experiments, the results of which enabled him to say that a much greater amount of power could be transmitted by electricity. During the past week, with a Gramme machine, 31 HP. had been transmitted, though only to a very short distance. There was scarcely any limit however to the distance to which power could be conducted, except that resulting from the loss necessarily produced by leakage and by the conductor. It remained to see how the losses from the various sources he had mentioned could be diminished, and what was the proportion of useful effect which might finally be looked for.

The facility of installation gave a great advantage to the transmission by electric cable in cases where a certain quantity of work was needed at once, or for temporary purposes. He did not think that the working of locomotives by electricity was likely to achieve any great success; but for working in the interior of mines he thought that the application of electricity by transmission along a fixed cable would produce extremely favourable results.

With regard to the cardinal question of useful effect, it had been laid down that with the dynamo-electric machines of Messrs. Gramme or Messrs. Siemens 80 per cent. of useful effect might be produced; but that did not express the practical value of the system for engineers. In a general way it might be said that 50 per cent. was the maximum of useful effect possible to be realised under present circumstances. At a distance of 500 or 1000 metres it was impossible to rely on a greater electrical efficiency than 60 or 70 per cent., or on a mechanical efficiency of more than 30 to 40 per cent. When the distance of transmission was great, the question became more complicated. With a locomotive on a railway, the power lost depended indeed on the condition of the roadway and rails, on the

weather, and on other circumstances; but it continued practically constant, and would be the same for the tenth mile as it was for the first. In electrical transmission it was different; there was a definite increase of loss through the cable for every additional mile run, and thus the useful effect steadily diminished as the distance increased.

In saying that electrical haulage need not be considered, the author, in his opinion, went too far. True, there was no satisfactory electric locomotive as yet, and exaggerated accounts of what was possible on that system must be disregarded. As he had said, 30 to 40 per cent. of useful mechanical effect was as much as could be secured at present; but great attention was now being given to diminishing the various losses, especially those due to increasing and reducing the speed. These losses were not accurately known; but in certain cases, where several belts and pulleys were necessary, he had found 20 per cent. to be lost in increasing the speed. Still this was a difficulty which was now known and could be faced, as also the other loss arising during transmission, which he had found in similar cases to amount to 10 per cent.; and these difficulties might be overcome, as those in the locomotive with regard to conduction of heat &c. had been overcome. On the whole he was now much more strong than he once had been in the view that any negative conclusion with regard to electrical transmission of power underground was at any rate premature.

Mr. CHARLES COCHRANE said it appeared to him that long tunnels, such as the St. Gothard, of which the drawings were before them, afforded a very useful application for electricity. He had had the opportunity of seeing the trial heading for the Channel tunnel at Dover, and was very pleased with the excellent way in which it was lighted at intervals of about 40 yards by electric lamps, the glasses being protected by wires to prevent accident. He considered that the same plan might very usefully be adopted in some tunnels on English railways. The author appeared to have overlooked the fact that, in Belgium at any rate, the engine-man was often working without having any sight of the mouth of

the pit, and entirely by the dial. It was almost staggering to observe how the man went on without seeing his cage delivered at the proper point, simply working by the dial. According to the requirements in England a man was obliged to have a view of the pit mouth, as well as of the dial itself. It was astonishing to watch the huge winding drum 10 metres in diameter, and having a circumferential speed of 550 metres per minute; yet the men seemed to have perfect confidence and to work it with the utmost precision.

By the leave of the meeting the following remarks by Mr. Killingworth Hedges were then read by the Secretary:—

Mr. Killingworth Hedges has read Mr. Bagot's paper with much interest, and regrets he is not able to attend the meeting. He cannot however agree with the author where he states "that no increased safety would be afforded by the electric illumination of the working face." In his opinion an incandescent electric lamp could be constructed to comply with the Mines' Regulation Act, in that it would be perfectly air-tight and so arranged that, if the glass were accidentally shattered, the electric continuity would be destroyed and the light extinguished before any explosive gas could be fired. An electric lamp which he has designed for a similar use has an exterior envelope of glass, between which and the fragile bulb a small quantity of water is inserted for the purpose of dispersing the light, and also by means of a simple arrangement to make electrical contact between the wires and the lamp, which floats on the water. On the breakage of the glass the water would immediately escape and extinguish the light. A lamp which would burn with safety in the presence of explosive gases would certainly give more security than the ordinary safety-lamps which occasionally light inside; also the electric lamp, from its superior illuminating power, could be placed at a greater distance from the work, and would not require to be moved so frequently. As regards the transmission of power by electricity, this has been successfully at work for some time at the mines of La Perronière in France, where

the electric power is taken from the pit's mouth to a considerable distance, and is there used to draw the coal tubs up an incline. The economy of such an application is entirely dependent on the cost of the original motive power; and doubtless the plan could be profitably employed in many cases.

Mr. Bagot, being absent through illness, has since sent the following observations, in reply upon the discussion:—

The point which the author wishes to insist upon is that, no matter how safe the electric lamp, the presence of gas is not indicated by it as by the safety-lamp. There is grave doubt whether the ignition of gas, when sufficiently diluted to be at the flashing or detonation point, would not take place with incandescent lamps surrounded with water. The point which none of the companies engaged in electric lighting will explain is how they propose to sub-divide the light in order to illuminate the working faces. The author would observe that the idea of surrounding an incandescent electric lamp with water was brought to his notice more than ten years ago, with a view to its adoption in mines. Mr. Cochrane is under some misapprehension with regard to the engine-man being obliged to see the pit-top in England. The Mines Regulation Act does not require it, and many, if not most, of the collieries, are worked entirely by the distance-indicator as in Belgium. The author so far agrees with M. Tresca in his observations, as that at some future date electric transmission of power is possible underground; but he wishes it to be understood that his own observations in the paper apply only to the present time. Exaggeration as to the capabilities of electricity has been carried too far; and he wishes to convey the true state of the case, as at present, to colliery managers. No doubt the loss of 30 to 40 per cent. of power in the operation of transmission will be overcome. He is indebted to M. Tresca for his classification of the causes of that loss of power, but at the present time he thinks compressed air more applicable underground than electricity. The exhaust from air engines is of such great practical value in fiery mines that, were the power equal, comparing electric and air haulage, he should prefer compressed air.

He wishes seriously to draw the attention of colliery managers to the danger of using mechanical signals. The fact that in deep shafts a signal once given cannot be countermanded before it has been acted on and an accident perhaps has taken place, should be sufficient to convince mining engineers that, where rapid winding is carried on, nothing but electric signals should be used, in justice to those employed. It is with this view that he has applied himself to perfecting a system of electric signalling which shall render mistakes and their grave consequences impossible; and a sufficient test of the system is that in seven years' use at one colliery, where some 5000 men are wound up and down daily, not a single accident has occurred.

ON COMPOUND LOCOMOTIVE ENGINES.

BY MR. FRANCIS W. WEBB, OF CREWE, VICE-PRESIDENT.

The object of the present paper is to show what advantages may be obtained by Compounding the Locomotive Engine, and how this may be practically carried out without materially adding to the weight or complicating the working parts. The subject is not a new one, as it has been dealt with in this Institution (Proceedings 1879, page 328) by M. Mallet, with regard to the Bayonne and Biarritz Railway. He succeeded in obtaining an economical engine, but in a form not likely to be a steady one at high speeds; great credit however is due to him for the attention he has given to the subject.

About five years ago the author converted an old outside-cylinder engine with 15-in. cylinders into a compound, on the plan adopted by M. Mallet, by lining up one of the cylinders and reducing it to 9 in. diameter. This engine has until the last three months been working light passenger trains on the Ashby and Nuneaton branch of the London and North Western Railway; and the elements of success seen in its working led to the construction of the compound locomotive "Experiment," which was what its name implies.

The two main objects the author had in view when designing the "Experiment" were—firstly to attain to greater economy in consumption of fuel; and secondly to do away with coupling-rods, while at the same time obtaining a greater weight for adhesion than would be possible on only one pair of driving wheels without rapid destruction of the road. The driving wheels being no longer coupled, there is less grinding action in passing round curves, and it is not even necessary that one pair should be of the same diameter as the other.

The engine "Experiment" was constructed at the Crewe locomotive works in the latter part of 1881, and has now been at work over twelve months and run nearly 100,000 miles, chiefly with the Scotch and Irish limited mails. While on this work it

made a daily run of 319 miles; and this being a longer mileage than the engines are accustomed to run in the time, two drivers and firemen were appointed to work the engine, one from Crewe to London and back one day, and the other the day following, in order thoroughly to test the engine in every way before building any more of a similar class. The engine has throughout proved itself to be very steady when running, which is no doubt due to the arrangement of the cylinders; the engine being practically balanced, and having no coupling-rods, is enabled to run at very high speeds.

The principle having been proved correct, it was thought advisable, owing to the increasing weight and the high speeds of passenger trains, that in designing the new engines they should be made more powerful than the present type. Accordingly the high-pressure cylinders have been increased from 11½ ins. to 13 ins. diam., leaving the low-pressure cylinder of 26 ins. diam. the same as at present, with the exception of the ports, which have been increased from 1½ ins. by 14 ins. to 2 ins. by 16 ins., in order to give more freedom for the exhaust.

The construction will be readily understood from the following description, and from the diagrams, Figs. 1 to 3, Plates 41 to 43. Of these, Fig. 1 is an elevation, with section through the high-pressure cylinder, Fig. 2 is a section through the low-pressure cylinder, and Fig. 3 is a plan. There are two outside high-pressure cylinders of 13 in. diam., Figs. 1 and 3, and one inside low-pressure cylinder of 26 in. diam., Figs. 2 and 3, the stroke in each case being the same, namely 24 in. The two high-pressure cylinders have their steam-chests placed underneath, in order to allow the valves to fall from their faces; so that there is no wear when the steam is shut off. These two cylinders are attached to the outside frame-plates immediately under the footplate, about midway between the leading and middle wheels, and are connected through their piston-rods and connecting-rods to wo cranks at right angles on the trailing wheels. The low-pressure cylinder, which has its steam-chest on the top, is placed directly over the leading axle, and is carried between two cross steel

plates, one at either end, securely fixed between the main frames; its connecting-rod lays hold of a single-throw crank on the axle of the middle pair of wheels.

The steam is supplied through the regulator in the dome A, Fig. 2, Plate 42, to a brass T pipe on the smoke-box tube-plate, and thence by two 3-in. copper steam-pipes B, running first parallel to the tube-plate, then through the back-plate that carries the low-pressure cylinder, and between the plates of the inside and outside frames, to the steam-chests of the high-pressure cylinders. The exhaust steam from these cylinders is returned by two 4-in. pipes C, running parallel with the high-pressure pipes, through the back-plate that carries the low-pressure cylinder, and into the smoke-box: following round the curved sides of the smoke-box nearly to the top, each pipe passes across to the opposite side, and enters the steam-chest of the low-pressure cylinder through passages in the cover. Thus the exhaust steam becomes superheated in these pipes by the waste gases in the smoke-box, while the large capacity of the pipes themselves obviates the necessity for a separate steam-receiver. The final exhaust escapes from each side of the steam-chest of the low-pressure cylinder into the blast-pipe, and thence to the chimney in the usual way, the only difference being that there are only half the number of blasts for urging the fire compared with an ordinary engine; yet the compound engine steams very freely, and has a blast-pipe of $4\frac{5}{8}$ in. diam. for the final exhaust, compared with $4\frac{1}{4}$ in. in engines of the ordinary type.

The steam-chest cover of the large cylinder is provided with a relief-valve D, Fig. 2, Plate 42, so adjusted that the pressure admitted may never exceed 75 lbs. per sq. in.; and a small pipe, connected to the low-pressure steam-pipe, and carried back to a gauge fixed inside the cab, shows at a glance the actual pressure of steam being used in the large cylinder. An arrangement is also made whereby steam direct from the boiler can be admitted to the low-pressure cylinder, which is useful for warming up before starting.

The valve-motion adopted for this engine is that designed by Mr. David Joy, and described at a former Meeting (see Proceedings 1880, p. 418), which does away with all eccentric-rods, and

considerably reduces the number of working parts per cylinder, as well as the weight of the valve-gear. The arrangement however for the new engines differs slightly from that on "Experiment," in order to do away with the trunnion bearings on the foot-plate. The total number of working or moving parts for the three sets of valve-motion in the compound engine is twenty-nine, and their total weight 284 lbs.; while the number of working parts in the two sets of valve-motion in the ordinary standard engine is twenty-four, and their weight 793 lbs.: the reversing shafts in each case not being taken into consideration. The valve-chests being on the underside of the high-pressure cylinders, the motion-discs E, Fig. 1, Plate 41, carrying the quadrant-bars, have to be placed in a corresponding position; and this is done by securing them to the underside of the slide-bars. The quadrant-bars, which are made of soft steel case-hardened, are each grooved to a radius equal to the length of the valve-rod link; and working in their grooves are brass slide-blocks I, carried by the lifting links G, to the lower end of which is attached the valve-rod link H, and to the upper end the compensating link J on the connecting-rod: the upper end of the compensating link is controlled by a rod K attached to a return crank on the trailing crank-pin. The quadrant bars are lengthened out below the discs, so as to allow attachment to be made, by the link L, with the reversing shaft placed behind the trailing wheels. The reversing is effected by means of a screw-and-lever arrangement connected to the reversing shaft.

The high-pressure slide-valves are of the Trick or Allen type, which gives double the lead shown at the edge of the port when the piston is at the end of its stroke; they have a travel of $3\frac{1}{8}$ in. in full forward and backward gear. The lap is $\frac{3}{4}$ in. and the lead $\frac{1}{8}$ in.; the port opens $\frac{3}{4}$ in. for admission, and closes at 70 per cent. of the stroke. The sizes of the ports in the cylinders are, for steam $1\frac{1}{8}$ in. $\times$ 9 in., exhaust $2\frac{1}{2}$ in. $\times$ 9 in.

The valve-motion of the low-pressure cylinder differs slightly from that of the high-pressure. Instead of discs there is a cast-iron shaft M, Figs. 2 and 3, Plates 42 and 43, carried in brackets, which are fixed to the inside frames; and the quadrant guides are bolted to

it in the middle of its length. The other parts of the motion are similar to those of the high-pressure cylinders, the only difference being that the end of the compensating link in the low-pressure motion is attached to a radius-rod N centred on the back-plate of the cylinder. At one end of the reversing shaft is fixed a lever, which is coupled direct by a long rod to the reversing handle on the footplate. The travel of the valve in full gear is $4\frac{1}{2}$ in., lap of valve 1 in., lead $\frac{3}{16}$ in.; the port opens 1 in. for admission, and is closed at 75 per cent. of the stroke, and the exhaust closes at 93 per cent. of the stroke. The sizes of the ports are, for steam 2 in. $\times$ 16 in., exhaust $3\frac{1}{4}$ in. $\times$ 16 in.

The reversing gears of the high- and low-pressure cylinders are designed to work independently of each other, and no inconvenience has been experienced by this arrangement; they could if desired be connected, but this would mean complicating the parts, while no material advantage would be gained.

With regard to the degree of expansion at which the engine is worked, in practice the low-pressure cylinder is kept nearly in full gear, while all the expansion is done in the small high-pressure cylinders, so that no more steam is used than is absolutely necessary to do the work.

The commercial results with the engine "Experiment" have been very satisfactory. During the time the engine was working the Irish mail from Crewe to London, and the limited Scotch mail from London to Crewe, the average consumption per train-mile was 26·6 lbs. of coal, compared with 34·6 lbs. the average consumption of the standard four-coupled passenger engines with 17 in. cylinders and 24 in. stroke, the boilers being precisely the same in each case.

One of the principal features in the new engines has been the adoption of a boiler with the water-space of the fire-box carried under the grate, Fig. 2, Plate 42, the space between it and the fire-bars forming the ashpan, just as in the case of the 18-in. goods engine which was fully described at the meeting of the Institution at Barrow (Proceedings 1880, p. 432). The object is to do away with the rigid foundation-ring, which is always a source of trouble; to obtain better circulation for the water; and to prevent

the lodgment of dirt on the sides of the fire-box where subject to the most intense heat. A flanged mouth-piece, similar to that of the fire-door, is formed in the centre of the water-space, and covered with sliding-doors worked from the footplate, so that the ashes can be easily removed or dropped; while any sediment that may collect in the water-space can readily be removed through the wash-out plugs in the sides of the fire-box, there being a clear passage from side to side when the covers are taken off. The mouth of the ashpan is made of such a width that the tube-plate can be taken out and replaced by a new one, without disturbing the other parts of the fire-box.

The principal features of the compound engine having thus been described, there are one or two other points to which a reference may be interesting. The leading axle, it will be noticed, is placed immediately under the large cylinder, Fig. 2, Plate 42, and nearly in a line with the centre of the chimney; consequently the wheel-base is longer than usual, the distance from leading to front driving-wheels being 9 ft. 4 in., and from front driving to trailing-wheels 8 ft. 3 in., making a total wheel-base of 17 ft. 7 in. To overcome the disadvantage attached to a long rigid wheel-base, the leading axle is provided with a radial box, Figs. 4 to 7, Plate 43, having a lateral movement of 1¼ in. to each side of the centre line of the engine. The box is formed in a single casting, with the brasses fitted in each end, and works between curved plate-guides A, stretching across from frame to frame. Inside the box and under the axle are carried two horizontal helical springs B and C, coiled right and left hand, and working one inside the other; so that when the engine enters a curve, the springs are compressed towards one side, and take any shock that may be transmitted through the wheels from the rails; and when the engine gets on to the straight again, the springs resume their normal position, and keep the engine central. This class of axle-box, but with two sets of side controlling springs,* has

* The single set of springs is a great improvement, as there is otherwise a possibility of side action, in case one set of springs breaks or is weaker than the other.

now been in use seven years with very good results (see Proceedings 1877, p. 307), and 155 engines are fitted with it, 40 of them having one at each end.

The journals of the axles, it will be seen, are long in each case. Those of the leading axle are 10 in. long and 6 in. diam.; while those of the front driving-axle are 13½ in. long and 7 in. diam., with crank journal 5½ in. long and 7¾ in. diam.; and the trailing-axle journals are 9 in. long and 7 in. diam. The advantage of these long journals has been amply proved in the running of the "Experiment."

The engine, although still working on the London section, has been taken off the Irish and Scotch mail trains, because it was not fitted with the gear for working the vacuum brake with which these trains are now provided, and it was not thought advisable to bring the engine into the shops for the present in order to apply the vacuum-brake gear. The new engines however are fitted with ejectors and all the necessary gear for working the vacuum brake; and in addition with a steam brake S, Fig. 2, Plate 42, acting between the two pairs of driving-wheels. This is also coupled to the tender brake-gear, so that the brake is applied to the engine and tender at the same time. A single movement of the driver's brake-handle serves to apply both the vacuum and the steam brake simultaneously; and similarly to release them together.

Indicator diagrams from the engine are shown in Figs. 8 and 9, Plate 44.

Appended is a statement of the leading dimensions &c. of these engines.

THREE-CYLINDER COMPOUND EXPRESS PASSENGER LOCOMOTIVE.

Cylinders.

Two High-pressure outside cylinders . .	Diameter	13 inches.
	Stroke	24 "
One Low-pressure inside cylinder . .	Diameter	26 "
	Stroke	24 "

Joy's Valve Motion.

Wheels.

	ft.	in.
Diameter of leading wheels, with radial axlebox . .	3	6
Diameter of front driving-wheels (low-pressure cylinder) .	6	6
Diameter of hind driving-wheels (high-pressure cylinders)	6	6
Distance between leading and front driving-wheels . .	9	4
Distance between front driving and hind driving-wheels .	8	3
Total wheel-base	17	7

Boiler.

	ft.	in.	
Length of barrel	9	10	
Mean diameter of barrel, outside	4	1 3/16	
Length of fire-box, inside . . 4 ft. 9⅛ in. at top	4	10½	at bottom.
Width " "	3	5½	
Height " from top of fire-bars to crown . .	5	5½	
Length of tubes between tube-plates	10	1	
Diameter of tubes, outside		1⅞	
Number of tubes	198		

Heating Surface.

Fire-box	103·5	square feet.
Tubes	980	"
Total	1083·5	"

Area of Fire-grate	17·1	square feet.

Ratio of heating surface to grate area = 63·35 to 1

Weight.

Weight of engine when empty		34·75 tons.
Weight of engine when in working order—		
Leading wheels	10·40 tons	
Front driving-wheels	14·20 tons	
Hind driving-wheels	13·15 tons	
Total . . .		37·75 tons.

In closing this paper the writer wishes to add, that his motive in laying before the Members of the Institution the particulars of his system of compounding locomotives is to draw attention to the subject and encourage its full investigation; as he feels assured that better economical results are to be obtained than those which he has already arrived at. He hopes therefore that other papers on the subject may be forthcoming in the future.

Abstract of Discussion on Compound Locomotive Engines.

The following communication from M. A. Mallet was read by leave of the meeting:—

M. MALLET wishes to express his great regret that he cannot be present at the meeting, in response to the kind invitation sent to him by the Council as the author of the paper on Compound Locomotives read in 1879.

In Mr. Webb's very interesting engine he considers that two points need special notice: first, the employment of the compound system generally; secondly, the division of the motive power between two sets of cylinders actuating different pairs of wheels, so as to do away with coupling-rods. The latter plan was tried on a large scale by the late M. Petiet, on the Northern Railway of France, and the results were by no means favourable; but there the cylinders were not compounded, and the fact of compounding them may perhaps justify a return to this system. The arrangement is however somewhat complicated, and if difficulties are found to arise in practice, these may possibly be attributed to the principle of compound action, whereas they may really be due to the special arrangement employed.

M. Mallet has always endeavoured to keep his own engines as similar as possible in arrangement to the ordinary type. He does not agree with Mr. Webb that they are unsuitable for high speeds; for whilst more economical they are no less stable than ordinary engines, which have always been found equal to the highest speeds required.

In any case M. Mallet is very glad to find himself no longer alone in supporting the cause of compound locomotives, and believes that the advocacy of so eminent an engineer as Mr. Webb will have a marked effect in establishing its success.

He thinks it right to add that his friend M. Jules Morandiere, as early as 1866, proposed a compound locomotive with three cylinders working two separate axles, on a similar principle to that now introduced by Mr. Webb. It was described in "Engineering" of 23rd Nov. 1866, p. 392, and in other papers.

Mr. W. E. RICH was glad that the important question of compound engines for locomotives had been brought before the Institution. He believed that the time was not very far distant when a large proportion of the high-pressure engines, used both in England and abroad, would of necessity perform their expansion in two cylinders instead of in one. About two years ago, at the request of the authorities of the Royal Agricultural Society, he had prepared a short paper for their Journal* upon the compound engine as applied to agricultural purposes, *i.e.* in portable engines, traction engines, and ploughing engines. He believed he was able to show, especially in the case of traction and ploughing engines, that very marked advantages might thereby be gained, not the least of which was that they would be able to run about one-third longer time and distance, or do one-third more work, with a given amount of fuel and water. This, considering the vicissitudes connected with the obtaining of both those commodities in the field or on the road, was a very important consideration. In such situations water was sometimes more difficult to get than fuel.

The case of the locomotive was, he thought, of equal importance. If a locomotive could be made to travel one-third or one-half longer distance with a given supply of water and fuel, not only the railway company but the public generally would be gainers; for they would be able to go, say from London to Liverpool, with fewer stoppages and in a shorter time. He did not know what was the proportion in a fast passenger engine of the weight of the fuel and water to that of the engine and tender; but one way of looking at it was this. Suppose the engine and tender to weigh, with the water in the boiler, 40 tons, and to carry 15 tons of fuel and water when fully loaded; then, if the compound engine would develop the necessary power with a quarter less steam, the heating and grate surfaces and consequently the weight of the furnace, boiler, and water in the boiler, might be reduced in the same proportion. Thus if the boiler, furnace, and water, formerly weighed 20 tons, 5 tons could be taken off their weight, and added to the spare fuel and water carried; and the

* See Journal of the Royal Agricultural Society, 1881, vol. xvii., p. 661.

engine would run without replenishing one-third longer distance than before. If however the original heating surface were retained, yet greater fuel economy would be gained, and the fire-grate might thus be reduced more than one-fourth.

He did not understand whether Mr. Webb's high-pressure cylinders worked on cranks at right angles; and he should like to ask the question. He was rather surprised to see the low-pressure cylinder only twice the diameter of the high-pressure cylinders; he should have thought that there would have been an advantage in making it rather more than that. With regard to the position of the slide-valve on the top of the low-pressure cylinder, he should be afraid that this cylinder, not being steam-jacketed, would have a tendency to harbour a great deal of water at the ends of the stroke. Perhaps Mr. Webb would state whether he had found any presence of water in the low-pressure cylinder when running, or whether he kept the drain-cocks open. In running an engine at a slow speed, water played an important part in reducing the economical use of steam with a low-pressure cylinder, when not steam-jacketed. A high-speed engine jerked the water out much more effectively than a low-speed engine; but a low-pressure cylinder not jacketed had always a tendency to retain water in it. Placing the slide-valve below, or low down at the side, would remove that tendency.

He had had no experience as to the efficiency of blast orifices; but he thought it possible that the longer interval between the blasts, mentioned in the paper, might not necessarily be productive of evil results. Too frequent blasts might act somewhat the same as a continuous blast, which was not as good as an intermittent one.

Looking at the indicator diagrams, Plate 44, he was much surprised to see the very uniform line of the exhaust in the high-pressure cylinder. He should like to know whether that was really the case, and that there was no wavy line in the high-pressure exhaust. There did not seem to be any large amount of receiver space between the cylinders; and it was surprising therefore to see so straight a line.

The arrangement of the cylinders in two sets with two sets of cranks was certainly a great novelty, having palpable merits even

at the first glance; and he could not but compliment Mr. Webb upon it. His first notion of a compound locomotive would have been to put a high-pressure cylinder in the centre, with two low-pressure cylinders at the sides, both working on cranks at the same angle, but at right angles to that of the high-pressure cylinder; then all would be in perfect balance at the two sides. But the avoidance of coupling-rods in Mr. Webb's engine was a new departure, and must be a great gain. He thought there would be a material gain by steam-jacketing the low-pressure cylinder, or in fact all three cylinders, if room could be found to allow of it; for the extra weight in the cylinder would be more than compensated by the reduced weight of the boiler to produce the same amount of steam.

M. A. Gottschalk said that, ever since the marine compound engine had proved so great a success, railway engineers had been urged to apply compounding to locomotives also. He had himself applauded the efforts made in this direction by his friend M. Mallet; and now he was glad to find that Mr. Webb had made a further step in advance. One of the advantages to be noted, beyond the economy of fuel, lay in the reduced wear of the engine and road. In England it was needless and useless to augment the number of coupled wheels; but the case was otherwise in mountainous countries. A very powerful engine, with six or eight wheels coupled, was there a necessity. When locomotive superintendent of the Southern Railway of Austria, he had in use upwards of a hundred locomotives with eight wheels coupled, working long inclines of 1 in 40, especially the Semmering, with curves of 180 m. radius (590 ft.); and he found that on those curves the rail heads wore down with great rapidity, while the leading tyres had to be changed after 40,000 kilom. (25,000 miles), instead of over 200,000 kilom. as on level lines. He believed however that Mr. Webb's system might be applied to such lines, coupling two sets of wheels to the high-pressure cylinders, and two to the low-pressure cylinder; and that the result would be an important saving, not only in fuel, but also in maintenance of road and rolling stock. The invention did the

greatest credit to its author, the engineer of those works at Crewe, from which so many good things in the way of railway improvements had already appeared.

Mr. T. R. Crampton had seen nothing, in any experiments yet made in compounding locomotives, which gave him sufficient data to form a judgment as to its economy. For many years he had been opposed, as a rule, to the multiplication of parts if it could be avoided. When the late Mr. Aveling started to make traction engines, he used to see a great deal of him; and he used to say to him, "Pray do not put more than one cylinder in your engines if you can help it; you do not want two parts, if you can make one do the work." And he believed that Mr. Aveling had carried that out to a greater extent than anybody else. That principle however had its limits; and the limit was at the point where the pieces for the simpler system became in some way too inconvenient for manufacture, or for use. Simplicity should be an axiom, but it should be an axiom used rightly. The comparison that had been made in the paper with the ordinary engine appeared to him to be of no value. It was a comparison between an ordinary engine and an engine with the same size of wheel, but with almost double the cylinder capacity to expand in. The area of two 17-in. cylinders, compared with one 26-in. cylinder and two 13-in., was about as 45 to 80. The result was that, if the indicator diagrams were drawn in each case, the area with the compound engine would be almost double that with the simple engine; and therefore the comparison was not a fair one. If it was desired to test a three-cylinder compound engine, it ought to be compared with a two-cylinder engine of the same capacity. But the question was in the hands of Mr. Webb; and they would no doubt have the right result in the end, for he never left a thing incomplete when he took it in hand. All that he desired to call attention to was the fact that the 20 per cent. economy was not due to the compounding, but was due to the extra expansion that was given.

He agreed very much with Mr. Webb in his endeavours to do away with coupling-rods. That had been a pet notion of his own for a

very long time. He went so far at one period as to propose to put a separate cylinder to each wheel. He had many drawings made with a single cylinder to each wheel, each wheel having its own axle turning in a separate box. Therefore his views were entirely in favour of doing away with coupling-rods. He had carried the system of uncoupled wheels as far as possible in his continental locomotives. Last year the engineer of the Strasbourg line came to him and said that his Company were just now investigating the question whether they should increase the number of their express trains, and retain the Crampton system without coupling-rods, or whether they should make new engines coupled, and so take heavier trains. They had statistics extending over 15 or 16 years, showing that the Crampton engines running their express trains compared so favourably with any engines that they had in France as to distance run, cost of repairs, and cost of fuel, that they thought it a very important point to consider whether they should not increase the number of trains and keep the uncoupled wheels, instead of having four wheels coupled and heavier trains.

M. A. BORODIN said he had studied Mr. Webb's locomotive with attention, and he thought that he was to be congratulated on his solution of the question. He wished to make one remark with regard to the construction, viz., that it seemed to him the locomotive had not so great a starting power as the ordinary locomotive; so that, if it were applied to heavy trains, there might occasionally be some difficulty in starting them. According to the positions shown in Figs. 1 and 2, Plates 41 and 42, there was but one piston—one of the two high-pressure pistons—which could start the engine, and that was of a smaller size than in the ordinary locomotive. He might add that this remark was not his own, but was due to Mr. M. N. Forney of New York, whom he had recently seen in America.

He could not agree with the conclusion of Mr. Webb's paper, which foretold that better mechanical results would be obtained from compound engines than had been obtained on this occasion. It appeared to him that better results could not possibly be obtained. The economy which had been shown was about 24 or 25 per cent.

Now the experiments which had been made by himself* with compound locomotives in Russia, and those made by M. Hirn, showed that it could not be hoped to obtain so large an economy from the compound principle only. All that could be hoped from the compound principle was about 15 or 18 per cent., in a high-pressure non-condensing engine. Part of the economy which had been obtained in Mr. Webb's case could perhaps be explained by the better arrangement and the better management of the engine; but he did not think that all the economy of 25 per cent. could be due to compounding alone.

Mr. Webb observed that some part of it arose from doing away with the coupling-rods.

M. Borodin said the day was at hand, in his opinion, when the compound principle would be generally adopted for locomotive engines; but his view was that they would not stop there. There were some engineers who said that the locomotive engine was a very perfect machine. He had seen a recent article by M. Marié, in the "Revue générale des Chemins de fer," pp. 403–413, 1883, stating that the present locomotive engines were so perfect that there was no hope of making any great improvement in them. He however thought the day was perhaps not very far distant when great improvements would be made. Experiments showed that the present locomotives consumed about 12 kg. of steam (26 lbs.) per IHP. per hour. With the compound principle he thought their locomotives would consume about 10½ kg. per hour. At the present time they had stationary engines which consumed only about 7½ or 8 kg. per HP. Those were certainly condensing engines; but he thought the day was not far distant (and he hoped to see it) when they would have a condensing locomotive of a simple and practicable construction.

Mr. David Joy said that he had had the advantage of being placed in the exceptional position of being able to see what most

* Proc. of the Société des Ingenieurs Civils, 1883, p. 162.

outsiders had not seen, that is, something of the progress of this, the most advanced step in locomotive practice which had been made for many years. And so he had been enabled to form an opinion on the subject from personal observation.

He thought that Mr. Webb's paper was before the Institution rather as a record of a completed success, than as a subject admitting of much discussion. The position above referred to had however frequently subjected him to the questionings of those interested in the matter, as to how far the generally reported statements really represented the advance or improvement made. He would therefore now enumerate what he considered to be the advantages which had really been secured.

First there was a substantial saving in fuel. He had been prepared for Mr. Webb's statement now made, that this was about 8 lbs. per train mile. From watching the fire and hearing the beat of the engine, any one on the foot-plate, accustomed to the running of locomotives, could easily tell that the engine was not burning the full amount of fuel that would be consumed by an ordinary engine running with the same load; and if in marine practice so much had been gained in economy by compounding, why should not the same results be obtained with a locomotive? The next point was the free running of the engine, from the absence of coupling-rods; and that was one of the great advantages. There could be no question that the engine ran as free as a single engine: you could not feel her take the curves, and there was an entire absence of the whistling and grinding which a coupled engine made when running round curves. So important was the question of accidents from coupling-rods becoming in the United States, that last year, at the meeting of the Master Mechanics' Association, a special paper had been read on the question of coupling-rods, in consequence of the fact that these were so continually breaking as the speeds increased. By Mr. Webb's plan coupling-rods were entirely done away with, so that that source of danger was removed. Again, with compounding, though high pressure was used, the initial strain upon the whole of the parts was reduced by the high-pressure steam passing first into the small high-pressure cylinders, and afterwards into the large

low-pressure. He had been further struck with the statement in Mr. Webb's paper, namely, that the engine had continuously run over 300 miles per day, and so required two sets of drivers. Now nothing was more against an engine than putting on two sets of men to work her; so that this showed there had been no nursing of the engine to obtain the results reported, which therefore were *bonâ fide*.

With regard to the separate reversing of the high- and low-pressure engines, he was not quite sure that he agreed with Mr. Webb. He admitted that the indicator diagrams shown were about as satisfactory as they could be; but the practice with marine engines was usually to cut off, both in the high- and low-pressure cylinders, at such points as to equalise the diagrams, giving equal power to the high and low pressures alike; and the results so obtained were usually considered to be the most satisfactory. Hence he was inclined to think this was not a settled question, but a proper subject for further investigation.

There was one question which had not, he thought, received sufficient attention, namely the question of the consumption of water. He had lately been designing some locomotives for South America, and one of the points requiring consideration was the reducing of the amount of the water to be consumed. Here, of course, compounding came in with great effect; and he expected that the engines, which were to be on Mr. Webb's compound system, would not only save 25 per cent. of fuel, but would save also the haulage of 25 per cent. of water. These engines had to start at the foot of a bank, but nearly all the work had to be done on a long level at the top of the bank, and the engines had to take all their water up with them, as there was none on the plateau. If therefore they could save 25 per cent. of the water as well as 25 per cent. of the fuel, a material advantage would be gained.

As to pressure of steam, Mr. Webb had retained the usual 150 lbs. per sq. in. On discussing the question he had suggested the adoption of a higher pressure, but had deferred to Mr. Webb's better judgment. Still he believed that with the compound system higher pressures would be employed, probably up to 200 lbs. per sq. in., and even that might not be the end.

M. J. MORANDIERE said he was not aware that his name would be mentioned by his friend M. Mallet. While thanking him for doing so, he must confess that the design made in 1866, of which M. Mallet had spoken, was a sketch merely, without any elaboration of details. The arrangement of Mr. Webb, besides having the sanction of experience, was obviously to be preferred for many reasons, among which he would mention the following. The three cylinders designed in 1866 had all the same diameter; the boiler steam entered the single central cylinder, and then passed on to the other two, where it was expanded. Hence in order to make sure of being always able to start, it was necessary to furnish a second steam valve, which would allow the steam, when needful, to be sent direct from the boiler into the two expansion cylinders. He would add that the idea of using three cylinders to work two sets of axles had been suggested to him by designs made on the Northern Railway of France, with the view of adding to the Crampton engine a third cylinder to work through a single crank on the axle of the middle pair of wheels.

He would take the opportunity of asking Mr. Webb how the indicator diagrams were taken, the instrument used, &c.

Mr. DRUITT HALPIN thought Mr. Webb had hardly done himself sufficient justice in the beginning of his paper, when stating that his design was intended to obtain greater economy in fuel and to do away with side rods. The further advantage to be gained by dividing the pressure between the cylinders was very great, and a great deal of the economy was no doubt due to that, as it was practically possible by means of the compound engine to use expansion to a degree which could not be attained with steam worked in a single cylinder. With regard to the radial axle-boxes, he could quite believe that Mr. Webb had had a great success with them. He had himself used them; they had run constantly over curves of 150 metres radius (490 ft.) for the last two years, with great success, and they were now using them for even sharper curves, of 100 m. radius (328 ft.).

He agreed with Mr. Rich with regard to jacketing. He thought

that jacketing, in the low-pressure cylinder particularly, would still further improve the engine. He supposed that Mr. Webb's objection would be the extra weight; and also that he got a certain amount of superheating in the receiver, which was placed in the smoke-box. If there was a proper amount of superheating it was a very good thing, and it might help to obviate the necessity for jackets; but it was possible to get too much superheating, and they knew what the result of that was. The importance of having jackets had been proved in the neighbourhood of Liége a short time ago by experiments made very accurately, and in which the matter was not complicated by the coal question; it was merely the water which was taken, and which gave all the results that were wanted. It was a spinning mill at Verviers, and the constructor guaranteed to do a certain duty with water. The test was made by M. Bède, and he found that he was considerably over the proper consumption of water. The engine was a horizontal compound with Sulzer valve-gear, having the cranks at right angles and an intermediate receiver; both the cylinders as well as the intermediate receiver being jacketed. The steam passed first into the jacket of the receiver, from thence into the jacket of the high-pressure cylinder, and from thence into the valve-chest. The low-pressure cylinder was jacketed with steam by a pipe led from the jacket of the intermediate receiver. The diameter of the small cylinder was 0·500 m. = 19·69 inches, that of the large cylinder 0·750 m. = 29·53 inches, and the stroke of both pistons 0·900 m. = 35·43 inches; the speed was 67 revolutions per minute. The engine was guaranteed, when working at 90 lbs. pressure, to develop one IHP. with 7·5 kilos = 16·5 lbs. of water, when working up to 190 IHP. When tested with a load of 126 HP., 9·7 kilos or 21·34 lbs. water were used; but the builder took exception to this test, as he contended the load was too light. A second test was therefore made with a load of 149·5 HP.; but the consumption of water rose to 10·4 kilos or 22·88 lbs. It was then evident something was seriously wrong; and on examination it was discovered that the steam traps, which were on the expansion principle, were not acting properly, and they were replaced by traps

actuated by floats. On a further test being made, with a load of 135 HP., the consumption of water fell to 6·889 kilos. or 15·16 lbs. water per IHP. per hour; the condensation in the jackets rose to 1344·3 kilos. or 2957 lbs. in a test lasting 8·725 hours; this was equal to 16·5 per cent. of the total water passing through the engine. The consumption of water (and to a greater extent that of coal) had thus been augmented by more than 51 per cent. by the improper working of the steam traps.

It would be exceedingly interesting if Mr. Webb would let them know what the consumption of water was in the new and in the old engines; and then they would have a very good comparison. The two boilers were identical, but in the case of the old engine the consumption of water was of course higher. The economy of the new engine was capable of being divided into two parts: one part was naturally due to the small range of temperature in each cylinder, but another part was due to the fact that the boiler was doing less work; there was thus less water evaporated per square foot of heating surface, and that had a considerable influence on the question.

M. Borodin, speaking of Russia, had said they were there working with 12 kilos. of water, or 26·4 lbs. per IHP. per hour. He himself had lately tested a small non-condensing compound engine, working with 100 lbs. boiler pressure, and found the consumption of water was 24 lbs. per IHP. per hour. He quite agreed with Mr. Webb that it would not be wise to reduce the boiler in size; it was better to obtain a greater economy by retaining the original size.

Referring to Mr. Crampton's remark about Mr. Aveling, he wished to observe that Mr. Aveling, at the last show at which he had ever exhibited (Derby 1881), showed a compound engine, and if he had lived no doubt he would have continued the practice. He could not agree with Mr. Joy in the view that it was possible to make non-condensing compound engines, like the one under discussion, give such good results as condensing engines. All steam engines were heat engines, and their efficiency therefore was dependent on the ranges of temperature between which they worked. Assuming a

condensing and a non-condensing engine to be each worked with 120 lbs. boiler pressure, taking the absolute back pressure in the condensing engine to be 2 lbs. per sq. in. and in the non-condensing engine 17 lbs. per sq. in., and omitting the effects due to condensation and re-evaporation in the cylinders, as well as to any fall of pressure in the intermediate receiver, the following comparison was obtained:—

120 lbs. pressure, Non-condensing.			120 lbs. pressure, Condensing.		
Absolute pressure.	Sensible temperature.	Absolute temperature.	Absolute pressure.	Sensible temperature.	Absolute temperature.
Lbs. per sq. in.	Deg. Fahr.	Deg. Fahr.	Lbs. per sq. in.	Deg. Fahr.	Deg. Fahr.
135 initial	350	811	135 initial	350	811
17 final	220	681	2 final	126	587
	130°	130°		224°	224°

This showed that the theoretical efficiencies of the two systems were in the ratio of 130: 224.

Mr. Alexander McDonnell said the principal thing he wished to do was to express his thanks to Mr. Webb for having tried this experiment, and tried it so well. There were very few railways that could afford to try experiments of that kind, and there were still fewer locomotive engineers who could carry them out in the way that Mr. Webb had done. There were a good many points besides the simple compounding of the engine which were exceedingly interesting, and they were all greatly obliged to Mr. Webb for having brought them so well before the Institution. He did not think that so much stress ought to be laid on doing away with coupling-rods. They had been at times very troublesome; but when an engine was well made, and the centering was properly attended to, the number of coupling-rods broken was not very large; and the difference in consumption between an engine with a single driving wheel and an engine with coupled wheels had not been shown

to be anything very remarkable. He did not know whether he exactly understood Mr. Crampton with regard to a single cylinder, but it appeared to him to be more a matter of convenience than anything else, whether the work could be best done with one plan or the other; he took it that in regard to locomotives most of them were clear that they could not do without two cylinders at least.

Mr. William Stroudley thought the locomotive engineers and the railway companies throughout the country owed Mr. Webb great thanks for the manner in which he had gone into this very important question. He believed that the economy to be derived from compounding engines had been thoroughly established. The value of the system had been admitted in regard to marine, stationary, and portable engines, and he thought there was no sufficient reason for saying that it would not be equally valuable in the case of locomotives. Although however the plan of the engine appeared to him to be a very satisfactory one, and well adapted to develop the value of compounding in a passenger engine, he did not think that a passenger engine was the best to try it with. Had the system been applied to a goods engine, he thought there would have been a much greater success. Mr. Webb's figures did not prove any very great degree of economy in the working of the engine. The passenger engines of the Brighton Railway showed for the last half year an average consumption of 25 lbs. of coal per mile, and he thought that the large quantity of coal placed against the ordinary engines on the London and North Western line was somewhat in excess of the average of railways doing similar work. He thought that a passenger engine running at high speed was the best possible form for the use of steam in a single cylinder or under the ordinary system; but a goods engine, working at low speeds, and during a very large part of its time with an admission of perhaps 70 per cent., was working under worse conditions than a passenger engine. He thought therefore that if Mr. Webb would apply his principle to a goods engine he would be able to show them hereafter still better results.

Mr. McDonnell asked Mr. Webb kindly to say what kind of coal he used. He supposed that the coal in the two engines was the same.

Mr. Crampton asked further for the quantity used in shunting and lighting up in both cases; so that the comparison might be as exact as possible.

Mr. Webb in reply, said he had not much to add, except in reply to the remarks made and questions asked. Replying to Mr. Rich, the cranks of the high-pressure cylinders were placed at right angles. With regard to the indicator diagrams, the exhaust line of the high-pressure cylinders was not always straight, but sometimes arched upwards in the middle of the stroke, which might be due to the low-pressure crank being in a different position relative to the two high-pressure cranks. Replying to M. Morandiere, the indicator diagrams were taken by two ordinary "Richards" indicators, with the connections made as close to the cylinder as possible; the motion was taken from the crossheads of the respective cylinders in the usual way; the diagrams were taken in pairs, from one of the high-pressure cylinders and from the low-pressure cylinder at the same time. Replying to Mr. McDonnell, the coal used in both engines was similar in quality, being principally South Wales steam coal, with sometimes a little North Wales main coal. Replying to Mr. Crampton, he could not give the coal used in shunting separately, but both engines being on similar work there could not be much difference: the lighting-up coal was also dealt with in the same way in both engines.

Since the paper was written they had turned out at Crewe ten compound locomotives of the same description as the one under discussion. A Sunday or two ago, he had had an opportunity of trying what these engines would do with the 10 o'clock express out of Euston, which on Sundays had eleven stoppages between Euston and Crewe, while the actual running time was much the same as for the 10 o'clock Scotch express on week days with only two stoppages. The compound engine took a train of 19 carriages, composite and

saloon, out of Euston to Crewe without assistance, and the time occupied in the run was 4 hours 30 minutes with the eleven stoppages. Last Monday the 10 o'clock Scotch express, which was one of the fastest trains running, was taken by the compound engine from Euston to Crewe in 3 hours 35 minutes with 16 large carriages, and with two stoppages.

Mr. Rich had asked the question whether there was any trouble with regard to condensation in the big cylinder. So far none had been experienced. The pipes between the two frames were packed in silicate cotton; so was the large cylinder. The whole space between the large cylinder and the frame was also packed with silicate cotton. With reference to the question of complication in the engine, he had only three connecting-rods, instead of the ordinary two coupling-rods and the two connecting-rods. He had thus one rod less, while he had an extra cylinder. The cylinder itself and the valve gearing were so simple that he thought if any member saw the engines themselves he would not say that there was undue complication. With regard to Mr. Crampton's remarks, he did not agree with his view; but he might say that it was in looking at an engine designed by Mr. Crampton—he believed it was when travelling on the Eastern Railway in France—that it occurred to him how easy it would be to utilise an extra portion of the weight of the engine for adhesion without coupling-rods; and that brought to his mind the design of the engine under discussion.

With reference to the question of carrying a sufficient quantity of fuel and water, they could carry sufficient coal to take them through from London to Carlisle, and it was of course well known to most English engineers that on the London and North Western line they picked up water wherever they required it, so that practically they were able to run an engine all the way through from London to Carlisle, and had done so on two or three occasions.

He might mention the first performance ever done by the compound engine "Experiment." Before it was painted, he hooked it on to assist a heavy express from Liverpool with 19 coaches. He tried it with the steam shut off from the other engine for some distance along the Trent valley. They ran without trouble from

Crewe to London; when the engine arrived in London it was all right, and he had it turned round and hooked on to the morning Irish mail, which it took to Holyhead. When the engine arrived at Holyhead it was still all right, and he then gave the men something to eat, turned the engine round and hooked it to the boat express, which it took to Crewe. The engine thus did 528 miles as a christening trip.

Mr. Stroudley had remarked that it would have been better if he had tried the system with a goods engine. One engine that he had in hand at the present time was for working on the Underground Railway, where there had lately been some discussion as to the amount of fuel consumed, and the nuisance arising from it. It was one of the engines originally designed by Mr. Fowler, and he had taken it in hand and was compounding it. Mr. Tomlinson would bear him out in saying that they had very sharp curves to run round on that line, and that very great trouble had been experienced with coupling-rods. Five or six years was all the life that could be got out of a coupling-rod on that line. He believed he had answered all the questions that had been asked. He thanked the members very much for the favourable hearing they had given him; and he trusted that the result would be that the fuel of locomotives would last a little longer in the future, with the increased economy which he believed would be brought about by compounding them.

ON THE CONSTRUCTION AND WORKING OF THE ST. GOTHARD RAILWAY.

By Herr E. WENDELSTEIN, of Lucerne.

It is proposed in the present paper to give some particulars as to the general Construction and Working of the St. Gothard Railway, exclusive of the great tunnel, which was dealt with in a former paper (Proceedings, 1883, p. 156).

I. General Design.

The general plan of the railway, from Lucerne to Biasca, is shown in Fig. 1, Plate 45, and indicates clearly the points where special expedients were necessary, namely Wasen on the north side, and Dazio and Giornico at the south.

The line from Lucerne to Brunnen need not be specially described. Eventually a new line will be carried from Lucerne along the shores of the lake to Immensee; but at present a detour is made by the Lake of Zug. From Brunnen the line is carried parallel to the well-known piece of road called the Axenstrasse, along the eastern shore of the Bay of Uri. The limestone peaks here sink at a very high angle into the lake, and send down several torrents, which in flood-time carry immense quantities of stones and mud. In some cases the line is taken across these torrent beds on a solidly built embankment, with a wide open span in the centre. In others it is carried under the torrent in a short tunnel. There are on the whole eight tunnels between Brunnen and Flüelen, occupying 5·3 km. (3·3 miles) out of the whole length of 11 km. (6·9 miles). When in the open the line is chiefly carried on a terrace cut along the steep face of the cliffs.

From Flüelen to Erstfeld the valley of the Reuss has the usual flat bottom of a glacier valley, and the construction of the line offers no difficulties. At Erstfeld the mountain section begins; the valley

narrows to a gorge, and its bottom rises by a succession of sharp ascents to the level of Göschenen. It was of course necessary that the railway should follow this rise, and that the trace should be so chosen as to minimise the dangers to which the working of an Alpine railway is always exposed. The chief of these dangers arise from the avalanches of earth and stones, which slide from the mountains into the valley, the fall of rocks from the cliffs, and the irruption of torrents in flood-time. Owing to these causes the ground at the bottom of the valley is always in danger of disturbance, and the circumstances thus differ widely from those of non-mountainous regions.

These facts seemed to point to the desirability of using, between Erstfeld and Amsteg, the right bank of the Reuss, where there is a tract of gently sloping and cultivated land, instead of the left bank, which is an unbroken range of steep cliffs. Above Amsteg, on the other hand, the most favourable ground is on the left bank as far as Pfaffensprung; while at Amsteg itself the narrow ravine of the Maderanerthal cuts into the main valley. The railway, after passing through a short tunnel, is carried over this ravine by the Kärstellenbach viaduct of two spans, and then, after crossing the Reuss, leads past the station of Gurtnellen to the Pfaffensprung tunnel; the line so far being tolerably straight, and the gradient not above 1 in 50.

From hence to the north portal of the great tunnel at Göschenen there is a vertical rise of 330 m. (1080 ft.) with a horizontal distance of 6700 m. (22,000 ft.). A gradient of 1 in 20 would therefore have been necessary if the railway had been taken straight up the valley. The maximum gradient fixed for the line was however 1 in 40; and some artificial lengthening was therefore a necessity. No lateral valleys offered themselves for the purpose, as on the Brenner and Semmering lines; and the choice therefore lay between employing zig-zags like those of an ordinary mountain-road, or spiral tunnels driven in the side of the valley. Another solution, which offered special advantages from the point of view of economy, was to concentrate the rise in a few inclines of steep gradient, which would have been worked by rack locomotives like those used on the Righi Railway and elsewhere; but it was considered that the

St. Gothard line would then have been placed at a disadvantage towards its competitors, as regards capacity for traffic, and would have forfeited the character of a great international line of communication. The spiral tunnels were on the whole preferred; and the first of these is the Pfaffensprung tunnel of 1500 m. length (1640 yds.). Above this the nature of the ground about Wasen enabled three lines to run parallel to each other for about 2 km. (1·2 mile); and advantage was taken of this to construct a gigantic zigzag, of which the arms were united by curves of about 300 m. (330 yds.) radius. As there was not room to make these curves in the open, they were for the most part constructed in tunnel, as shown.

By means of this zigzag and the Pfaffensprung spiral tunnel, the line reaches such a height that it is only necessary thenceforward to follow the line of the valley in order to obtain the proper level at Göschenen. The total length of the line as laid, from the entrance of the Pfaffensprung tunnel to that of the great tunnel, is 14,700 m. (9·13 miles), as against 6700 m. (4·16 miles) the horizontal distance.

On the southern side of the great tunnel the ground was more favourable for the railway; except at three points, namely the gorges of Stalvedro, Dazio, and Giornico, where the bottom of the valley falls rapidly in a sort of step. The first of these is the shortest, and it is avoided by means of a tunnel on the right bank of the Ticino, without any special lengthening of the line. At Dazio however there is a fall of 160 m. (525 ft.) in about 2000 m. (6560 ft.); and it was necessary therefore to lengthen the line about 4000 m. (13,120 ft.) if the railway was not to reach Faido at a great height above the floor of the valley. The steep cliffs on each side forbade the construction of a zigzag like that at Wasen; and the lengthening was accomplished by two spiral tunnels, each 1500 m. (1640 yds.) long. The first is on the left bank, at the entrance of the gorge; on emerging from it the line crosses the river by a lofty viaduct to a sort of terrace on the right bank, which leads it to a second tunnel at the exit of the gorge.

Again at Giornico there was a fall of 117 m. (384 ft.) in a length of 700 m. (2300 ft.), and hence a lengthening of the line by 4100 m. (13,400 ft.) became necessary. It was at first proposed to effect

this by a long zigzag; but it was found that this would actually cost more than the spiral-tunnel method, on account of the torrents which poured down the left-hand slope, where the line must have lain, and which in flood-time were exceptionally destructive. The railway is therefore taken partly in terrace, partly in the open, through the gorge, and just at its exit passes through two spiral tunnels in rapid succession, each of them about 1500 m. long (1650 yds.). From thence, by adopting a slightly steeper gradient, namely 2·7 per cent. or 1 in 37, the line was able to follow the fall of the valley to Biasca, where it loses the character of a mountain railway.

II. General Construction.

The line is of normal gauge (4 ft. 8½ in.). The maximum gradient is 2·7 per cent. (1 in 37) on the mountain section, and 1 in 100 on the valley section. The minimum radius for curves is 300 m. (328 yds.); and the stations are so placed as to lie always on a straight section. The main point of importance in laying the line was to secure it against avalanches, falls of stones, and torrents. In general this was accomplished by the position chosen for the line; but where this was not possible, works of protection were resorted to. In the most dangerous places tunnels or galleries were constructed; and the torrents were crossed by lofty bridges of great span. In less perilous places embankments or loose walls were erected above the line, as a protection against stones and snow. The width in cutting at rail-level is 7 m. (22 ft.) with flat slopes of 1 to 1½; but in cuttings between rock walls under 3 m. high (10 ft.) the width was narrowed to 6·60 m. (21·6 ft.), whilst deeper rock-cuttings were widened to a maximum of 9 m. (25·9 ft.). The walls were vertical, where the nature and bedding of the rock permitted; but if this showed signs of weathering it was cut to a slope of 1 to 1. In loose earth, slopes of 1 to 1½ were frequent; but in firmer soil, such as old moraines, 1 to 1 was considered sufficient. Such slopes were planted with diagonal lines of fascines to prevent waste of the surface, and this with great success. When loose earth lay over rock, on a slope above the line, it was kept back by a retaining wall, as shown in Fig. 2, Plate 46.

The embankments were made usually to a slope of 1 to 1½, sometimes to a slope of 1 to 1¼. The latter, where stone was plentiful, were faced with a layer of rubble 0·60 m. thick (2 ft.). In some cases the downhill side of the embankment was formed entirely of packed stone, rising sometimes to a height of 20 m. (65 ft.) In other cases walls of loose stone laid in courses at a steeper angle, say 3 to 2, were employed. In special cases, where the hillside was very steep, and the bedding sloped downwards and outwards, as in Fig. 3, Plate 46, vertical retaining walls were built, backed up with rubble, and the line was laid on the top.

Where the height of the walls became excessive, arched viaducts were adopted, with spans varying from 7 to 14 m. (23 to 46 ft.). The piers of these were often founded on isolated points of rock standing out of the drift. In other cases they were built on the solid rock. Figs. 4 and 5, Plate 46, show an elevation and cross-section of such a viaduct, where the fall sideways was too steep to allow of an ordinary culvert. Where the foundations were bad for piers, or the height too great, iron bridges of greater span were resorted to; but these generally had a row of masonry arches at each end. The elevation and sections, Plate 47, of the Kärstellenbach viaduct already mentioned show a good example of this construction. The kind of girder adopted was decided by local conditions, so as to be most convenient for the putting together in place and the final erection.

The ballast has a thickness of 0·35 to 0·40 m. (13·8 to 15·8 in.), and in the cuttings of 0·50 m. (19·7 in.). The width at the level of the rails is 3·40 m. (11·15 ft.) in the valley section, and 3·60 m. (11·81 ft.) in the mountain section. Where stone was plentiful the sides of the formation were formed of loose rubble walls.

The permanent way consists of steel rails 36·60 kg. per m. run (72 lb. per yard). The length of the rails is 8 m. (26·24 ft.). They are fastened by dogs to sleepers, 2·40 m. by 0·24 m. by 0·15 m. (8·2 ft. by 9·41 in. by 5·9 in.), and placed 0·91 m. apart on the valley section and 0·81 m. apart on the mountain section (3 ft. and 2 ft. 8 in.). On the latter the sleepers are of oak and larch, on the former of fir and pine. On the north side they are pickled with chloride of zinc, on the south with sublimate of mercury.

All the stations on the mountain section are provided with water-

tanks, which, except in two cases, are supplied by streams without the aid of pumps. Every station is supplied with home and starting signals connected with the points, and also with distant signals. The line is fenced throughout, a measure rendered necessary by the number of cattle which are pastured along the route.

Some statistics of the construction of the line may be given here. The length, exclusive of the great tunnel and the valley section on the southern side, is 160 km. (100 miles). It was finished within three years, at a cost below the figure of 67,392,000 francs (£2,695,680) which had been estimated. The excellent stone of the mountains passed through proved of great use for the immense quantity of masonry required on such a line. The fears which had been expressed, that it might be difficult to find sufficient men to do the work required at a given point and at a given time, proved groundless, chiefly because Italy furnished an almost boundless supply of railway workmen, and also because few other lines were in progress at the time when these approaches were under construction. The number of men employed daily, which at the commencement of the work in 1879 was 1455, reached in August 1880 its maximum of 14,459, and at the end of the work in 1881 was still 9373; the average number from October 1879 to October 1880 was 10,757.

It is rather the great number of special works than their size or importance which is the feature of this line. Amongst these may be specially mentioned the host of tunnels, which were estimated to cost a total sum of 30,266,173 francs (£1,210,647). Including galleries, there were fifty-one tunnels (besides the great tunnel), having a total length of 24,208 m. (15·1 miles). The cost was therefore on an average 1250 francs per metre run (£45 7*s.* 6*d.* per yard). The more important of these are as follows:—

Name of Tunnel.	Length. m.	Length. yds.
Oelberg, at Brunnen	1941	2123
Monte Cenere	1673	1830
Naxberg, at Göschenen	1570	1717
Freggio Spiral Tunnel, above Faido	1569	1716
Prato " "	1559	1705
Travi " above Giornico	1547	1692
Piano Tondo " "	1508	1649
Pfaffensprung " below Wasen	1476	1614

The part of the line which lies in the open has a length of 135·5 k. (84·2 miles), and was estimated to cost, exclusive of permanent way, 27,125,827 francs (£1,085,033), or 201,767 francs per kilometer (£12,873 per mile). The actual cost however was less. In this length there were 969 bridges and other works of construction, which required 295,410 cub. m. (386,435 cub. yds.) of masonry. This includes 223 bridges and culverts made in iron to a weight of 6634 tons. Out of the cuttings there were taken 4,827,450 cub. m. (6,314,315 cub. yds.) of earth and rock, most of which was employed for the embankments along the line. Great part of the excavation was of stone sufficiently good to be employed for the rubble used in facing the slopes and building the retaining walls, the amount of which was 205,000 cub. m, (268,140 cub. yds.). This amount was partly supplied by the boulders which were met with along the line.

The most important of the iron bridges are given in Table I. on the following page.

III.—TUNNELLING.

With reference to the spiral tunnels the writer proposes to confine himself to a description of the Pfaffensprung tunnel, the lowest on the northern side. This tunnel, which is 1460 m. in length (1600 yds.), is remarkable as having been driven chiefly by the Brandt drill, which is a rotary drill worked by hydraulic power. This drill has since been employed with great success at the eastern end of the Arlberg tunnel.

The apparatus required for the Brandt drill consists of two high pressure pumps with differential pistons, driven by a turbine; of an accumulator; and of a regulating valve, intended to regulate the pressure and prevent shocks, both within the drill itself and in the pipe leading to it. This pipe is of wrought-iron 38 mm. in diameter (1½ inch). The joints are made by screwed sleeves A, Fig. 7, Plate 48, which pass over the ends of the pipes. A copper ring B is fitted between the ends, each of which is brought to a sharp edge entering a groove in the copper. The ends being screwed left- and right-hand respectively, the tendency of the sleeve is to draw the two ends together, thus causing them to bite into the copper and make a

TABLE I.—PRINCIPAL IRON BRIDGES.

Name of Bridge.	Spans. No.	Spans. Metres.	Spans. Feet.	Weight of Iron. Tonnes.
Inschi Reuss	1	77	253	334·64
Untere Tessin (Giornico) . . .	4	2 of 14·8 2 of 45·0	2 of 49 2 of 148	258·82
Kärstellenbach	2	50	164	268·75
Mittlere Mayen Reuss . . .	1	65	213	241·39
Göschener Reuss	1	65	213	241·78
Polmengo	1	65	213	241·77
Brenno	2	50	164	241·15
Rohrbach (arched)	1	60	197	236·56
Zgraggenthal	3	30	98	165·16
Obere Mayen Reuss	1	56	184	158·13
Obere Tessin (Giornico) . . .	1	50	164	156·28
Kellerbach	2	35	115	153·84
Tessin (Stalvedro)	1	50	164	134·12
Obere Wattinger Reuss . . .	1	44·9	147	129·16
Piano Tondo	4	25·8	85	126·87
Tessin (Dazio grande)	1	45	148	126·78
Loibach	1	40	131	90·95
Inschialpbach	1	40	131	85·50
Travi	3	20	66	61·02
Vallone	1	30	98	57·59
Häggrigerbach	1	30	98	55·80

firm joint. The pressure is 80 to 100 atmospheres, or from 1200 to 1500 lbs. per sq. in.

The machine itself is shown in Figs. 8 to 10, Plates 48 to 50, in plan, elevation, and longitudinal section.

A socket piece G, which is movable about a piece F connected to a horizontal shaft N, carries the boring cylinder O. Within the cylinder is a hollow plunger I, which is pushed forwards by the pressure, and forces against the rock a steel drill M, Fig. 8, screwed on the piston-rod Q. The total pressure on the drill is from 10,000 to 12,000 kil. (10 to 12 tons). To the socket G are attached two

small hydraulic motors D and E, of about 13 H.P. each; these actuate by cranks a shaft carrying a worm J. This worm gears with a worm-wheel H, turning loose upon the cylinder O. The wheel H is solid with the outside cylindrical casing P, on which slide the piston-rod guides; the rotation of the casing by the wheel H accordingly turns the piston and piston-rod, and therefore the drill itself, at a speed of 7 to 10 revolutions per min.

The shank of the drill is of steel, and hollow, having a diameter of about 64 mm. ($2\frac{1}{2}$ in.), whilst the cutting edge or crown is widened out to about $2\frac{3}{4}$ in. diam. This edge has four teeth like a saw, carefully hardened; the teeth are re-sharpened as they wear down. The shank is made in pieces of a fixed length, which can be easily screwed one on to the other as required.

The working of the machine is carried on by means of the valve-chest B, which contains a single stop-cock Z admitting the pressure-water simultaneously into the branch-pipe leading to each of the motors D and E; and a two-way cock Y for producing the forward or backward movement of the drill-plunger I. By opening this cock the pressure of water is admitted through the pipe U to the rear of the plunger, where it acts upon the full area of the plunger to press the drill forwards against the rock; and on closing the cock the drill is drawn back by the water pressure acting constantly upon the small annular area in front of the plunger-piston through the pipe R. By partly closing the cock Y, the pressure on the rear of the plunger and therefore upon the drill can be moderated.

The attention required is so small that one man can easily manage two or more machines.

The hole can be washed out, to clear it of débris, by closing the cock C in the pipe leading from the motors to the escape-hose S. The exhaust water from the engines, instead of escaping at once, is then led through the copper-pipe V, into a pipe running along the centre of the cylinder O, and opening into the inside of the plunger I. From thence it passes along the hollow piston-rod and drill, and escapes at the face.

The supporting-shaft N consists of a tube with a plunger fitted in it. By admitting the pressure-water to the interior, the plunger-

head is forced out against the side of the heading, and the shaft is thus set fast. The plunger can be withdrawn by means of a two-way cock, in the same way as that of the working cylinder. The shaft and drills are carried on a small wheeled-truck, and are counterbalanced so as to be in equilibrium when the shaft is not fixed. The shaft can be swung round parallel to the line of the heading, so as to occupy less room when advancing or retiring.

The mode of operation with the machine is as follows.

The truck having been brought up to the face of the heading, a distributing piece with connecting lengths between is screwed on to the end of the main-pressure pipe. A copper pipe transmits the water-pressure from the main to the shaft N. This shaft is swung round across the heading at a distance from 5 to 6 ft. behind the face, and a turn of the cock is sufficient to fix it to the sides. The drills are then connected by other pipes to the distributing piece, and directed to the proper points of the face. The stop-cocks are then opened and the boring commences. The total feed of the drill is 9·84 in. When its full range has been reached, the two-way cock is closed so as to withdraw the drill, and another length is screwed on to the shank. The operation is thus continued until the hole has reached a depth of from 40 to 48 ins. The depth to which a drill will bore before it requires sharpening depends of course upon the hardness of the rock. In the granite and quartzite of the Pfaffensprung tunnel, this depth varied from 8 to 20 ins., but in limestone or dolomite it has reached 10 m. (32·8 ft.). The number of holes pierced at one time varies from four to six. As soon as they are finished, the drills are withdrawn, while the charging commences. When the shots have been fired, water from the pressure main is projected through a pipe with a rose on the end against the face of the working, and serves both to absorb the fumes of the dynamite and to cool the air.

The efficiency of the Brandt drill may be judged of from the particulars in the annexed Table II., which relate to its performance in the very hard rock of the Pfaffensprung tunnel, in the spring of 1880.

The driving of the Pfaffensprung tunnel was commenced by hand, and a heading of 67 m. long (220 ft.) at the north end and 34 m.

(112 ft.) at the south end was so driven. The first machine-drill used was on the Frölich system, worked by compressed air; and the following Table III. gives a comparison of the work done by this system and by hand-labour, with the work subsequently done in the same tunnel by the Brandt hydraulic drill. It will be seen that

Table II.—Work of the Brandt Drill in the Pfaffensprung Tunnel.

Particulars per Month.		1880. April.	1880. May.	1880. June.
Nature of rock (granite gneiss)		hard	hard	compact
Mean transverse section of heading	sq. m.	7·0	6·5	6·0
	sq. ft.	75·35	69·97	64·59
Total advance during month	m.	58·8	61·7	44·6
	ft.	192·9	202·4	146·3
Number of machines working together		2	2	2
" attacks		73	56	53
" hours worked		700	612	610
" machines withdrawn for repairs		1	1	0
" drills changed for sharpening		2124	1586	2638
Mean pressure of water at heading	atm.	100	100	100
Dynamite used	kg.	935	589	702
	lb.	2060	1300	1550
Particulars per Day.				
Mean advance of heading	m.	1·96	1·99	1·49
	ft.	6·43	6·53	4·89
Maximum "	m.	3·00	4·00	3·70
	ft.	9·84	13·12	12·13
Particulars per Attack.				
Mean advance of heading, for one attack	m.	0·80	1·10	0·84
	ft.	2·62	3·61	2·76
Time occupied: Drilling	hr. m.	5·56	6·07	8·01
Time occupied: Removing spoil	hr. m.	3·42	4·55	3·29
Time occupied: Total	hr. m.	9·38	11·02	11·30
Mean number of holes drilled		6·10	6·25	7·37
Mean depth of holes	m.	1·05	1·15	1·04
	ft.	3·44	3·77	3·41
Mean diameter of holes	mm.	70	70	70
	in.	2·75	2·75	2·75
Particulars per metre advance of heading.				
Number of attacks		1·24	0·91	1·19
Time occupied: Drilling	hr. m.	7·21	5·34	9·32
Time occupied: Removing spoil	hr. m.	4·35	4·23	4·08
Time occupied: Total	hr. m.	11·56	9·57	13·40
Mean number of holes drilled		7·50	5·67	8·78
Number of machines withdrawn for repairs		0·02	0·02	0·00
" drills changed		36·12	29·80	59·00
Dynamite used	kg.	15·90	9·55	15·70
	lb.	34·98	21·01	34·54

after three months' use of the Frölich drill, during which time there had been several accidents, the progress was not equal to that which had been laid down in the estimate; and it was for this reason that the Brandt drill was substituted.

TABLE III.

Daily Advance.	Frölich Drill.			Brandt Drill.			Hand-working. North End.			Hand-working. South End.		
	Date.	M.	Ft.	Date.	M.	Ft.	Date.	M.	Ft.	Date.	M.	Ft.
Minimum	Dec. 79	1·0	3·28	July 80	1·5	4·92	July 79	0·4	1·31	July 79	0·4	1·31
Maximum	Jan. 80	1·3	4·26	Dec. 80	2·6	8·53	Feb. 79	0·8	2·62	Feb. 79	0·9	2·95
Average		1·18	3·87		2·05	6·73		0·61	2·00		0·66	2·16

The variation in the progress between the minimum and maximum here shown depends of course on the nature of the rock. Although the rock in this tunnel was of the hardest character, yet, thanks to the employment of the Brandt drill and of the English method of driving (namely by making the leading heading at the bottom), this tunnel was completed more quickly than any of the other spiral tunnels. These were mainly driven by means of the Frölich drill. On the whole it may be considered that the Pfaffensprung tunnel, 1476 m. long (1614 yds.), was completed in two-and-a-half years' work.

4. Ventilation.

The question of ventilation, which was omitted from the former paper, has now to be considered, as applying both to the great tunnel and to the other tunnels on the line. A distinction must be drawn at starting between the ventilation during construction, and the ventilation when the tunnel is completed. With regard to the former, it is of the utmost importance that during the construction of a long tunnel the workmen should receive the greatest possible quantity of fresh air, not only for breathing, but also for cooling purposes. If this supply is not sufficient, the power both of men and of animals is very greatly diminished, and the work of the tunnel is increased both in time and in cost, and may even be brought to a standstill.

The mode in which air was admitted to the great tunnel during construction has been described in the former paper. The Mont Cenis tunnel, which was driven by the bottom-heading system, had met with considerable difficulties as to ventilation at certain places; and in the St. Gothard tunnel a higher temperature was to be expected. This was the main reason why the top-heading system was chosen for the St. Gothard tunnel. It was hoped that as the whole upper part of the tunnel could thus be completed more rapidly, a natural ventilation would be produced which would materially assist matters; this however was not found to be the case until the headings were united. Natural ventilation can only extend to a certain length in a heading closed at the far end; and here the irregularity of the section at the various points where work was going on occasioned an additional difficulty.

The following Table IV. gives the temperatures in the leading heading on the north side of the St. Gothard tunnel for the years 1873 to 1880:—

TABLE IV.

Year.	Length of Heading.		Temperature.	
	Metres.	Miles.	Cent.	Fahr.
1873	570	0·354	15·00	59·00
1874	1300	0·808	19·72	67·50
1875	2800	1·740	22·61	72·70
1876	3800	2·361	19·22	66·60
1877	4400	2·734	22·60	72·68
—	4600	2·858	22·67	72·74
—	5200	3·231	24·40	75·92
1878	6000	3·728	25·70	78·26
1879	6900	4·288	27·60	81·68
—	7100	4·412	28·50	83·30
—	7300	4·536	29·78	85·60
1880	7500	4·660	31·00	87·80

The increase in temperature as the heading advanced in length is seen to be very great. This is due partly of course to the greater difficulty of cooling the longer heading, but mainly to the increased depth below the surface. It will be noticed that there was an actual fall of temperature in the year 1876, due to the fact that the heading was then passing under the plain of Andermatt, and that the depth below the surface was therefore diminished.* In February 1880, just before the meeting of the headings from north and south, the temperature, augmented by the crowding together of men and lights, rose as high as 34° Cent. (93·2° Fahr.). The hottest point was at some distance behind the face of the heading, since at the latter the cold air escaping from the boring machines had its maximum effect. The heat however was not so injurious to the energy of the men and the horses as the foulness of the air, mixed as it was with the explosive products of the dynamite, with steam, with smoke from the lamps, and with other exhalations. The heat in fact was not more than had been expected, judging from the experience of the Mont Cenis tunnel; but the greater length of heading at the St. Gothard seriously increased the evil. The result was an immense diminution in the work done per person employed, especially just before the meeting of the headings, which took place on 29 Feb. 1880. In addition to the loss of a number of horses, several men were killed by the dynamite gases, and many suffered from a disease which was traced by medical men to the presence of a hitherto unknown species of intestinal worm. At that time the number of men employed daily on the two headings was over 2000, together with 70 horses; and assuming that the work done by each was diminished by one half, which is probably below the fact, it will be seen how greatly both the time and cost expended in completing the headings were increased by the unfavourable conditions of the air. The men worked in three shifts of eight hours each; and it is calculated that about 400 men with 300 lamps were continually at work in each heading. About 350 kilograms of dynamite (785 lbs.)

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* The average rise in temperature in the rock itself may be taken as 2° C. for each 100 m. depth below the surface (1·11° F. for each 100 ft.).

were fired daily. At the same time fresh air was poured daily into the tunnel, to the extent of 120,000 cubic metres per day at atmospheric pressure (4,476,000 cubic ft.).

The proper ventilation of the working places was greatly injured by the distance over which they were extended. The distance absolutely necessary with the top-heading system of driving amounted to 2 km. (1¼ mile). When the air in these working places became very bad, the workmen relieved themselves by boring holes in the pipe which was conducting air, at six atmospheres effective pressure, to the machine drills. This of course reduced the air pressure at the drills and the amount of work done by it, and yet did not afford a sufficiently good atmosphere to the workmen. The water power available was not sufficient to supply complete ventilation by the aid of air compressed to a high pressure. Theoretically the compression and delivery into the main of one cubic metre of air requires, to give an effective pressure of 0·2 atmosphere, a power of 1900 kg.-m. (14,500 ft.-lbs.), and to give an effective pressure of 6 atmospheres a power of 22,000 kg.-m. (159,000 ft.-lbs.). Now as regards ventilation, it is the same thing whether the air comes through small pipes at a high pressure or through larger pipes at a lower pressure. Hence at the St. Gothard tunnel it would have been better, as is done at the Arlberg, to supply the air which was not required for the drills in pipes of 0·4 to 0·5 m. diameter (16 to 20 in.) up to the part of the tunnel where work was going on, and from thenceforward in pipes of 0·3 m. (12 in.). Had that been done, it would have been sufficient if the air intended for ventilation had been compressed to only 0·2 atmosphere effective pressure, as at the Arlberg, instead of to 6 atmospheres as at the St. Gothard; and with only the same expenditure of power the ventilation would then have been 11½ times better. Unfortunately the top-heading system, which was selected for the St. Gothard tunnel, prevented the possibility of introducing and frequently relaying special pipes for the purpose of ventilation.

Turning now to the spiral tunnels, we will again take the Pfaffensprung tunnel as an example. The curve of this tunnel penetrates 700 m. (765 yds.) into the mountain, and its maximum

depth below the surface of the mountain is 440 m. (1443 ft.). The increase in temperature was found to be at the rate of 1° C. for every 32 m. measured along the shortest line to the surface (1° F. for every 58 ft.). A little before the junction of the headings the temperatures at the face of the heading were as follows:—19° to 20° C. = 66° to 68° F. during the drilling; 22° C.=71·6° F. after firing the shot; and 22° to 23° C. = 71·6° to 73·4° F. during the loading up of the rock. These were the maximum temperatures; at the same time the temperature outside was 11° C.=51·8° F. For a certain distance within the tunnel there was a natural ventilation, due to the fact that there was always a difference between the mean temperature in the tunnel and that of the air outside. In consequence the colder outside air flowed in along the floor of the tunnel, and becoming warmed within the tunnel flowed out again along the roof. A little before the final completion of the tunnel this ventilation extended to about 500 m. (550 yds.) from the entrance; but further in the air seemed nearly stagnant. So long as the Frölich drill was at work with compressed air, this supplied a sufficient artificial ventilation; but when the Brandt hydraulic drill was substituted, this no longer existed. The compressors employed for the drill however were afterwards used almost entirely for ventilation, and besides these a four-bladed centrifugal fan was placed in the engine-house as an additional ventilator. From this ventilating pipes of galvanised iron 0·22 m. in diameter (8⅝ in.) were laid into the tunnel, at first to a distance of 450 m. (500 yds.) from the entrance, but afterwards close up to the face of the heading, where they were connected with a radial apparatus. A second line of pipes was laid from the compressors up to the working places. These pipes were of wrought-iron; they were at the first 100 mm. internal diameter (4 in.) and 4 mm. thick (0·16 in.); in the middle they were 75 mm. diameter (3 in.), and 3 mm. thick (0·12 in.); and at the end 52 mm. diameter (2 in.) and 2½ mm. thick (0·10 in.) During the drilling the passage of air to the working places was almost shut off, in order that more air might be supplied to the place where the last shot had been fired and the *débris* was being removed; before any shot was fired however, the pipes were fully opened at that spot. The clearing away of the

smoke &c. was facilitated by showers of spray discharged by the pressure-water pipes. By these various means the ventilation during construction was kept in a normal condition.

We will now proceed to the question of ventilation after completion. In the great tunnel the temperature on both sides in the two halves is largely influenced by the natural current of air which prevails at any given time. A current from the south cools the southern half and heats the northern; whilst a current from the north has the converse effect. About the middle of the tunnel the fluctuations in temperature are altogether insignificant. From August 1881, when most of the timber &c. within the tunnel was withdrawn, the temperature at the middle fell rapidly from 30·4° C. = 86·7° F. to 28·9° C. = 84·0° F., and again to 27·4° C. = 81·3° F. by the beginning of September, and to 20·5° C. = 68·9° F. by the beginning of November. The average temperature of the rock in the whole tunnel was originally 23·43° C. = 74·2° F.; but on 29 Feb. 1880, after the junction of the headings, this average temperature was 21·69° C. = 71·1° F., whilst on 11 Feb. 1881 it was 19·30° C. = 66·7° F., and on 24 Feb. 1882 it was 14·15° C. = 57·5° F. These figures, referring to the same month in three successive years, show the very great fall in the general temperature of the whole tunnel.

The moisture of the air within the tunnel, which had a very bad effect on the workmen during construction, has largely diminished since its completion. In Feb. 1881 the relative moisture at the centre of the tunnel was still 98 to 100 per cent. of saturation; but it has now fallen to 81 per cent., although towards the middle of the southern half it rises rapidly to as much as 95 to 100 per cent.

With respect to the ventilation as at present, the following principles must be taken into consideration. Firstly, the level of the two portals differs by 36 m. (118 ft.); and in consequence there is a difference in the pressure due to the difference between the weight of two columns of air of this height, one at the temperature outside the tunnel and the other at the inside temperature. If the temperature outside were always lower than inside, and if the barometer stood always at exactly the same height at both ends

of the tunnel, then if there were no resistances this difference in pressure would produce a continuous flow of air from the north to the south, inasmuch as the northern portal is the lower.

Secondly, as a matter of fact there is always a difference in the height of the barometer, or the pressure of the air, at the two ends of the tunnel. If the barometer is higher at the northern than at the southern end, there will be a current from north to south, and *vice versâ*. This difference in the atmospheric pressure will either increase or diminish, and sometimes reverse, the current due to the cause last described. As a matter of fact this second cause is found to be the principal one; and the difference of level between the two portals acts only to increase or diminish the current due to the difference in the barometer. The resistances to this current are caused partly by the expansion of the air in the heat of the tunnel, and partly by the friction against the walls. Calculation has shown that in the period from 29 Feb. 1880, when the headings were united, to 14 April 1880, the resistances within the tunnel were so great that only 0·7 per cent. of the air which would have entered in the absence of all resistances actually penetrated to the centre of the tunnel. Between 18 Sept. 1880 and 11 Feb. 1881 this proportion rose to 1·9 per cent.; and in Feb. 1882, when all obstacles had been withdrawn, the proportion was 8 per cent., or eleven times greater than it had been previously. Further observations are required to determine the value of this factor under all circumstances.

An important matter with regard to ventilation is still to be considered. This is the change which occurs in the direction of the current, when the atmospheric conditions at the two ends of the tunnel are reversed. At such times there must of course be a period, more or less long, without any current, and when consequently no ventilation is taking place. In order to determine the influence of this cause in the future, meteorological observations have been made both outside and within the tunnel, and have been carefully analysed. Taking the data given for the year 1881, and assuming the above coefficient of 8 per cent., it appears that if the tunnel had been completed in that year the maximum speed of current in each month would have been on the average 3·74 m. (12·27 ft.) per second, and

the minimum 0·51 m. (1·67 ft.); that on the average a northerly current with a speed of 2·61 m. (8·56 ft.) per second would have prevailed for 191 days in the year, a southerly current of 2·02 m. (6·63 ft.) per second for 87 days, and an alternating current for 87 days also. The northerly current fortunately prevails during the summer months, May to September. There would have been during the year 37 single alternations of direction, while 18 times in the year there would have been alternations on two successive days, once on three successive days, and twice on four successive days. A single alternation is unimportant, as the period of no current, lasts only for a small fraction of the day; and the fresh current, which follows, speedily clears the tunnel of the foul gases, chiefly carbonic acid and carbonic oxide, which have gathered in it. Thus at the present rate of traffic it requires a current of only 1 m. (3·28 ft.) per second to clear the whole tunnel once a day. Moreover at the Mont Cenis tunnel, which is much less favourably situated, a current of 2 m. (6·56 ft.) per second is found quite sufficient with the full traffic. At the St. Gothard tunnel, as we have seen above, the average current is about 2·61 m. (8·56 ft.) per second. Even if the reversals of the current recur more frequently, the ventilation does not altogether cease; and it would be only in the event of the ventilation being stopped for four successive days by such reversals that the atmosphere might approach the limit of foulness which could be breathed with safety. This could scarcely happen more than once or twice a year; and on such occasions it would be possible to suspend a part of the goods traffic for a short time. It follows therefore that natural ventilation is sufficient in the case of this tunnel, and that no artificial means need be resorted to. This however is partially due to the fact that the St. Gothard tunnel is a much more favourable tunnel than Mont Cenis as to natural ventilation; the gradients are also much easier, so that the same amount of products of combustion need not be discharged in the tunnel. The air-compressors employed at Mont Cenis produce but a slight effect upon the ventilation of the tunnel itself, their use being mainly to supply fresh air to the men's quarters.

The above considerations were put forward when the tunnel was

first opened; and the results of working have altogether confirmed them. At present about twenty-six trains pass through the tunnel daily, thirteen each way. Ten of these are passenger and sixteen are goods trains. It was feared that with this traffic ventilation would become difficult, and various expedients were proposed for the purpose. It was even suggested that bags of oxygen should be carried on the engine for the benefit of the driver, and a scheme was seriously discussed for working the trains by electric locomotives; but no such devices are found to be necessary. There is in fact always a difference in the barometic pressure on the two sides of the main chain of the Alps, and therefore at the two ends of the tunnel. This difference is sufficient to produce a definite current of air in one direction or the other. Thus, supposing the pressure to be highest on the north side of the chain, an engine-driver entering the tunnel at that end finds the air for at least half the distance perfectly clear and fresh. For the remainder of the journey there is a mist sufficient to prevent lights from being seen at any great distance, and the air is somewhat heavy and close; but there is no discomfort from impure gases, and the air is in every way superior to that in many other tunnels. Very often the tunnel is so clear that either end of it can be seen from the middle of its length. Thanks to this current of air, the temperature in the middle of the tunnel is now only 17° C. (62·6° F.), instead of 31° C. (87·8° F.) at which it stood when the two headings were united. The laying of the second line of rails, which has been accomplished in the spring of this year by a large number of men and with the full traffic running, was carried out with ease by aid of the natural ventilation only. Thus has the problem of ventilating so long a tunnel been solved by the operation of nature alone.

We may now turn to the spiral tunnels, as to which similar fears were expressed, especially with regard to the very difficult conditions under which the traffic is conveyed through them. Here again however, unfavourable predictions have been falsified, and natural ventilation is found to be quite sufficient. From a descending train there is practically no emission of smoke; and an ascending train has to contend only with the smoke produced by its own engine.

Nothing is necessary for the passengers to do but to close the windows; and in cold weather even this is unnecessary, as the smoke then passes over the tops of the carriages. In hot weather, and in tunnels of smaller section, the air is naturally warmer, and therefore not so much heavier than the hot gases as to keep them up against the roof; they then fill the whole area of the tunnel, but fortunately seldom for so long a time as in any way to impede the working of the line. It is an advantage in the St. Gothard railway, as compared for instance with the line over the Apennines from Bologna to Pistoja, that the tunnels lie at altitudes where the temperature is comparatively low.

It appears then that the curved form of the spiral tunnels does not as a matter of fact create any special difficulty with regard to ventilation. At the same time, the steep gradients on which these and most of the other tunnels are situated are an advantage for ventilation, inasmuch as the difference in level at the two ends causes the tunnel in some degree to act as a chimney, and produces a current of air more or less rapid. On the other hand, these steep gradients require a larger amount of work from the engines, and consequently involve a larger discharge of gas into the tunnel, necessitating therefore a greater amount of ventilation. It must not be forgotten however that the passage of the trains produces a disturbance in the air, and is thus the cause of a considerable current. Observations made by Herr A. Trautweiler * have shown that a current of 0·5 m. (1·64 ft.) per second (1·12 mile per hour) is sufficient to change the air throughout a tunnel of 1500 m. length (1640 yds.), or about the length of any of the five spiral tunnels, in fifty minutes; and the current of air is generally considerably more rapid than this. This is shown by the following figures:—in the Wattinger tunnel a difference of 2° C. = 3·6° F. between the average temperature inside and outside the tunnel produced a current of 0·4 m. (1·31 ft.) per second; in the Leggistein tunnel, of about the same length, 1100 m. (1203 yds.), a difference of 1·4° C. = 2·5° F. produced a current of 0·7 m. (2·30 ft.) per second; here the wind must have given some assistance. In the Freggio and Prato tunnels observations

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were made on a perfectly windless day; and here differences in temperature of 0·8° C. = 1·4° F. and 1·2° C. = 2·2° F. produced currents of 0·5 m. (1·64 ft.) and 0·7 m. (2·30 ft.) respectively. At the Monte Cenere tunnel a strong south-east wind was blowing full against the higher of the two portals at the time of the observations; nevertheless with a difference in temperature of 1° C. = 1·8° F. the air streamed out from that end of the tunnel at a speed of 0·4 m. (1·31 ft.) per second. On the whole it appears that tunnels which have their gradients in the same direction have also the same direction of ventilation. At temperatures outside of 13° C. = 55° F. to 16° C. = 61° F. ventilation is nearly absent; at higher temperatures there is a downward current, and at lower temperatures an upward current. In all these cases the natural tendency is more or less interfered with by conditions of atmospheric pressure. In the spiral tunnels the direction of the wind is unimportant, as the two portals are close together and face in the same direction; but the observations at the Monte Cenere tunnel show that the natural current can overcome a considerable wind.

The traffic through the tunnel has of course an important influence on the ventilation. Observations however show that the air current is influenced by the passage of the trains to an extent of 25 per cent. only, and this sometimes in a favourable and sometimes in an unfavourable manner. Special observations were made on this point on the Pfaffensprung tunnel. A train entering the tunnel with a speed of 8 to 12 m. per second (18 to 27 miles per hour) acts as a sort of piston, and its motion produces a current of air which, according to the section and length of the tunnel, will have from one-fourth to one-third the velocity of the train itself. The natural current of air is thereby for the moment suspended, and only comes into play again after the train has made its exit from the tunnel.

Now there are four modes in which the natural current can combine with that due to the train.

1. *Train ascending, with current ascending.*—During the passage of the train, the tunnel air has a speed of 2·0 m. to 2·5 m. per second (6·56 to 8·20 ft. per second or 4½ to 5½ miles per hour), so as almost to blow a candle out. When the train makes its exit, about

three-quarters of the length is still filled with smoke; from that moment the speed of the air current decreases, and after five or ten minutes has fallen to its normal rate. By this time the column of foul air has so far advanced that only half the tunnel is occupied by it. The natural current of 1·5 m. per second (4·92 ft. per second or 3·36 miles per hour) is sufficient to clear this off in about seventeen minutes. In this case the heating of the tunnel air by the products of combustion tends to increase the current. At a point in the tunnel where the normal temperature was 11·2° C. = 52·2° F., it rose to 19° C. = 66·2° F. on the passage of an ascending goods train with two engines, and took eight minutes before it fell to its old value. Near the train however the air in this case is free from smoke; but behind it the tunnel air and the burnt gases mix immediately, and breathing is difficult. Assuming a consumption of coal of 100 kg. per kilometer (355 lbs. per mile) for two engines together, and a tunnel section of 35 sq. m. (377 sq. ft.), it appears that the air behind the train will contain about 0·8 per cent. of carbonic acid.

2. *Train descending, against current ascending.*—The descending train emits no smoke, but it disturbs for a time the previously ascending current of air. If the tunnel still contains smoke from a previous ascending train, this smoke will probably follow the descending train down to below midway in the length of the tunnel, before turning back again towards the upper end. The clearing of the tunnel is thereby considerably delayed.

3. *Train descending, with current descending.*—This is the most favourable case. There will be no emission of smoke, and any foul air still in the tunnel will be cleared out all the more quickly.

4. *Train ascending, against current descending.*—This is the least favourable case. The reversal of the current by the train lasts for eight to twelve minutes, and then the old downward current regains its supremacy. The smoke, which probably still fills the upper half length of the tunnel, then turns back, and flows out very slowly through the lower portal. Assuming a current of 0·8 m. per second (2·62 ft.), it will take forty minutes after the train has left the tunnel before the air gets completely cleared. If however a

descending train comes during this period it will considerably assist in the expulsion of smoke.

The whole of the above applies to tunnels on steep gradients. In tunnels where the gradient is less than 1 in 100, the current is determined chiefly by the wind. Such tunnels are generally constructed parallel to the valley and fairly straight. Hence the wind blows almost always directly through them, and there is scarcely ever a cessation of ventilation. Moreover the line being nearly level, the smoke emitted is not great. The current produced by the train itself, which lasts some little time after its exit, also assists the ventilation. This is especially the case in tunnels made for one line of way. In these the resistance to the air is much greater and the ventilation more difficult; but the effect of the train is much more powerful. In the longer tunnels upon the Lake of Lucerne the mean temperature has been observed to be 13° C. = 55·4° F. when the external temperature was 14° C. = 57·2° F. The average temperature within such tunnels lies between the mean annual temperature of the locality and the external temperature at the time, but somewhat nearer the latter.

As a general conclusion it may be stated that in long tunnels the condition of the air will be better as the gradients are less steep, since the evils due to the emission of smoke are greater than the advantages gained through the augmentation of the current by the steeper gradient. For this reason the steep gradient of 0·8 per cent. (1 in 125) proposed for the Simplon tunnel over a length of 10 km. (6¼ miles) appears to require further consideration. Again, the current caused by the train itself is of course important, and would be almost sufficient for the ventilation of a level tunnel. It is most desirable that a tunnel should be cold, in order that the escaping gases may keep as long as possible in the roof, above the train. For this reason the winter is a more favourable time than the summer for the efficient ventilation of tunnels.

5. Rolling Stock.

The St. Gothard Railway possesses at present 81 locomotives to work its system, which has now a length of 266 kil. (165 miles). They are divided into classes as follows:—

Class A.—Ten tank engines—nine of them 4-coupled, one 6-coupled. Of these eight are shunting engines, and have a weight loaded of 25 to 29 tons full, and 19·2 to 23 tons empty. The heavier of these are also used to haul mixed trains on the valley sections. The other two are small engines, weighing 14·9 tons full and 12 tons empty. They work the branch from Bellinzona to Locarno.

Class B.—Fourteen 4-coupled engines, half of which are tank engines, weighing 46·5 tons full and 35·7 tons empty; while the other half have tenders, and weigh, including these, 53·4 tons full and 38·4 tons empty. These engines work the express and passenger trains on the valley sections.

Class C.—Thirty-four 6-coupled engines, twenty-two of them being tender engines, and the rest tank engines. Of the former there are six which, including the tender, weigh 56·8 tons full and 48·8 tons empty. The other sixteen weigh 67 tons full and 46·5 empty. The twelve tank engines weigh 56·2 tons full and 41·2 empty. This class work the goods trains on the valley sections and the passenger trains on the mountain sections.

Class D.—Twenty-three 8-coupled engines; weighing with tender 77 tons full, 58·5 tons empty. These engines work the goods trains on the mountain sections.

The maximum speed prescribed for each of these classes is as follows:

Class A—50 kil. per hour (31 miles).
Class B—75 „ „ (47 „).
Class C—60 „ „ (37 „).
Class D—45 „ „ (28 „).

The following Tables V. and VI. give the weights of trains which these various engines can haul on the different sections of the line, and when going in both directions. These weights have at times been considerably surpassed in practice.

In the year 1882 only part of the line was in work up to the 1st June, the date when the mountain section was opened for traffic. Hence no complete figures can be given as to the actual performances of the engines.

TABLE V.

Weight of Trains that can be hauled, going from North to South.

Type of Engine.	Class A.			Class B.			Class C. Nos. 41–46.			Class C. Nos. 51–66 and 81–88.				Class D.		
Sections of Line as below.	Passenger Trains.	Mixed Trains.	Goods Trains.	Express Trains.	Passenger Trains.	Mixed Trains.	Passenger Trains.	Mixed Trains.	Goods Trains.	Express Trains.	Passenger Trains.	Mixed Trains.	Goods Trains.	Passenger Trains.	Mixed Trains.	Goods Trains.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Luzern-Erstfeld .	—	180	200	160	180	200	260	340	380	—	260	340	380	—	400	500
Erstfeld-Göschenen .	50	60	70	55	60	—	100	110	120	110	120	125	135	140	155	170
Göschenen-Airolo .	160	200	240	190	210	220	240	260	300	240	260	300	350	280	320	400
Airolo-Biasca . .	160	200	240*	190	210	260	240	260	300	240	260	300	350	280	320	400*
Biasca-Giubiasco .	200	220	240	250	260	280	300	340	400	—	300	340	400	—	500	600
Giubiasco-Bironico .	60	70	80	60	70	—	110	120	130	110	120	130	140	140	160	170
Bironico-Taverne .	200	220	240*	190	210	260	270	260	300	240	300	340	400	340	400	500*
Taverne-Chiasso .	120	160	180	120	160	180	180	190	210	180	190	210	230	—	270	300
Bellinzona-Luino .	160	200	220	160	180	200	240	320	340	—	260	340	380	—	500	540
Cadenazzo-Locarno .	160	200	220	160	180	200	240	320	340	—	260	340	380	—	500	540

* The weights marked for these descending gradients are only admissible when the brakes are complete according to order and are in good condition.

TABLE VI.

Weight of Trains that can be hauled, going from South to North.

Type of Engine.	Class A.			Class B.			Class C. Nos. 41–46.			Class C. Nos. 51–66 and 81–88.				Class D.		
Sections of Line as below.	Passenger Trains.	Mixed Trains.	Goods Trains.	Express Trains.	Passenger Trains.	Mixed Trains.	Passenger Trains.	Mixed Trains.	Goods Trains.	Express Trains.	Passenger Trains.	Mixed Trains.	Goods Trains.	Passenger Trains.	Mixed Trains.	Goods Trains.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Locarno-Cadenazzo .	150	180	200	160	180	200	240	300	340	—	240	300	340	—	400	500
Luino-Bellinzona .	150	180	200	160	180	200	240	300	340	—	240	300	340	—	400	500
Chiasso-Taverne .	100	120	140	100	120	140	180	190	210	180	190	210	230	—	260	280
Taverne-Bironico .	70	80	90	70	80	90	150	160	170	160	170	180	180	150	170	200
Bironico-Giubiasco .	150	180	200*	150	200	240	240	260	300	240	260	300	350	280	320	400*
Giubiasco-Biasca .	150	180	200	160	180	200	240	300	340	260	270	300	350	—	400	500
Biasco-Airolo . .	60	70	80	55	60	—	100	110	120	110	120	125	135	140	155	170
Airolo-Göschenen .	150	180	200	190	210	260	240	300	340	240	300	340	400	300	400	500
Göschenen-Erstfeld.	150	180	200	190	210	260	240	260	300	240	260	300	350	280	320	400*
Erstfeld-Luzern .	150	180	200	170	190	220	240	300	340	—	260	340	380	—	400	500

* The weights marked for these descending gradients are only admissible when the brakes are complete according to order and are in good condition.

In the construction of the engines it was necessary to take account of the fact that the railway has many sharp curves, 300 m. (328 yds.) being the minimum radius. To enable the engines to run round these easily, the overhanging weight was diminished as far as possible. Space does not allow of a detailed description of the engines.* The fuel used is, for passenger trains, patent fuel from the Ruhr; for goods trains, a mixture of coal from the Ruhr and Saarbruck districts. This arrangement is found to give the best results.

The carriages belonging to the railway are at present as follows:—46 first class, 21 first and second class, 54 second class, 61 third class, and 1 invalid carriage. The whole of the above are four-wheeled coaches. To those must be added 12 eight-wheeled third-class carriages, making 195 coaches in all. The number of places is as follows:

First class	1047
Second „	2417
Third „	3664
Total . .	7128

There are also 694 luggage vans and goods wagons.

The carriages are chiefly on the improved American system. The first-class carriages have an outside platform with verandah, to enable passengers to enjoy the view. All the carriages are lighted with gas, and warmed with hot air.

The express trains are fitted with continuous non-automatic vacuum brakes on the Hardy system. Electrical contact instruments are provided at intervals on the line, to regulate the speed of the trains.

* For diagrams of the various classes, and for drawings of the 8-coupled engines, Class D, see 'The Engineer' for Nov. 17th, 1882, pp. 368 and 369, and Dec. 29th, 1882, p. 481.

Abstract of Discussion on the St. Gothard Railway.

M. Trasenster said that the chief interest of the communication related to the St. Gothard Tunnel, but much of the success attending that work was due to the experience gained in boring the Mont Cenis Tunnel. A Belgian engineer, M. Mans, now Honorary Director General, had conceived the first idea of that great enterprise; but it was M. Sommeiller who first thought of applying air, compressed by water-power furnished from natural sources, to the mechanical perforation of rock; and he came to Seraing to obtain the appliances required for the boring of the tunnel. He was a man of immense intelligence and talent, and he had the honour of being the first to carry out to a conclusion so large an enterprise. During the whole time of its execution it was constantly necessary for him to modify and improve the appliances employed; and the Society Cockerill, who supplied all the mechanical appliances, actively seconded his efforts. At first they did not work with drilling machines faster than could be done by hand; but at the end they had attained a speed eight or nine times as great. In the making of the St. Gothard Tunnel the engineers had availed themselves of the experience acquired in connection with Mont Cenis. The construction of the drills at first was extremely complicated, but by the Brandt system a great advantage had been obtained, in the utilisation of the water-pressure, which diminished the complication of the mechanism, as required for the transmission of force by compressed air. In drilling by percussion there were always shocks, producing serious loss of power; but here the work was done by a comparatively slow rotary motion with a high pressure; and this was exactly suited to water, which was adapted for very great pressure, but had too much inertia to be applicable at high speed. In consequence of the improved appliances at the St. Gothard and the Arlberg tunnels, the working had been more rapid than at Mont Cenis. He believed that a wide field was now opened for engineers in that direction, and that mountains would no longer be an obstacle to free

communication between different countries. The information given by the author was extremely interesting, and their thanks were due to him for his excellent communication.

Mr. E. P. RATHBONE remarked that the Brandt hydraulic drill appeared likely to be very advantageous for the working of mines, especially in high mountain districts. He had lately been in Bolivia, at a place called Potosi, situated some 14,000 feet above the level of the sea, where fuel was very scarce, in fact so scarce as almost to preclude the possibility of raising steam for motive power on any large scale. There were great riches to be had in the shape of silver ores, but scarcity of labour and of fuel made it very expensive to work them. One of the great questions considered was whether it was possible to use air-compressors at such a height, owing to the rarity of the atmosphere. It had been found that owing to that cause it was necessary to have three or four times the heating surface in a boiler to produce the same effect as at ordinary levels. There was however abundance of water-power in the district, and he thought under these circumstances the employment of the hydraulic drill in that district could not but prove a very great economical advantage.

The PRESIDENT, referring to the application of the hydraulic system for rock-drilling, said that he believed he had on a former occasion alluded to a hydraulic drill which he had introduced many years ago at the Allenhead lead mines in Northumberland, where there was a water pressure of about 850 lbs. per sq. in., and an adit through which the exhaust water could run away. The idea of employing hydraulic machinery for drilling was quite a new one at that time. The principle on which he then went had certainly in a measure been reproduced in the machine now under discussion. The method of holding the drill to the face of the rock by pressure had occurred to him; and for this reason, that if a drill was held firmly against the rock with a pressure before cutting, a good deal of breakage and wear upon the cutting edge of the drill was saved. The drill was held against the face of the rock with a pressure of

about one ton on the cutting face of the tool; and the effect was good, as the drills lasted a long time. The method also of anchoring the machine by means of rams he had found to answer extremely well. From the interest he took in hydraulic machinery he was very glad to see that a hydraulic drill was really coming to the fore. The arrangement seemed to him on the whole to be a good one, but no doubt it would be improved upon in time. Herr Wendelstein, he regretted to say, was not present. This was the second paper he had given to the Institution upon the subject, and he was quite sure that the members would accord him a very hearty vote of thanks for the trouble he had taken.

ON THE NEW HARBOUR WORKS AT ANTWERP.

BY M. G. A. ROYERS, ENGINEER TO THE MUNICIPALITY OF ANTWERP.

Before describing the important Harbour Works now under construction at Antwerp, the author will devote a few words to the situation and history of the port. It is not necessary to carry our researches far into the past; we need go no farther than the beginning of the present century to find a condition of things which was merely the embryo of that which now exists. There were no docks properly so called, and scarcely any quays. In front of the town was a foreshore, which was partly dry at low water, and on which vessels lay; and besides this there were half a dozen creeks opening into the river, but also dry at low tide. The position of Antwerp is however so favourable, and the river on which it stands offers so many advantages for navigation, that freedom was the only thing required to create, or rather to restore, a maritime trade of great importance. These natural advantages have grown with time. The great depth of the river, which was formerly a mere superfluity, is now a notable element of the town's prosperity, in consequence of the continually increasing draught of vessels, and the growing importance of saving time in discharging. Canals, roads, and above all railways, have still further increased the importance of the position of Antwerp, which may now be considered as one of the most advantageous in the world from a commercial point of view. Nevertheless, all is not yet complete: the river is excellent as regards navigation; but measures must be taken to preserve its depth, and if possible to improve it. Navigation may be interrupted in the middle of winter,—not that the Scheldt is actually closed, but that steering becomes difficult; and although this inconvenience is reduced to an interval of some five days per annum on an average, yet it should be still further diminished, or, if possible, done away

with altogether. The railways needed have not all as yet been made, and the possible improvements have not all been introduced; nevertheless, despite the efforts of competition, progress has been so extremely rapid, beyond that of other places, that at present the trade is doubling every eight or ten years. Glancing back at the trade existing at the commencement of this century, we see that the development has been immense,—nay even in 1850 the tonnage entering the port was only 250,000 tons, while in 1865 it was 750,000 tons, and in 1882 it had reached the figure of 3,450,000 tons.

The period of the Consulate and Empire is that which marked the execution of the first important works in the harbour, including two lengths of quay upon the Scheldt, and the two first docks, now called the Old Docks, constructed by Napoleon (see Fig. 1, Plate 51). Of these the smaller, or entrance basin, is about 150 metres wide (490 ft.) and 173 metres long (567 ft.); the large basin was 402 metres long and 173 metres wide (1320 ft. and 567 ft.), but has lately been reduced to 380 by 150 metres (1240 by 490 ft.) in order to enlarge the quays. These docks were well constructed, and joined to the Scheldt by a lock of 18 metres width (59 ft.); and these, with some lengths of quay wall, in all about 1500 metres (5000 ft.), and the creeks mentioned above, were sufficient for the trade until 1843. At that date a new length of quay wall, about 350 metres long (1150 ft.), was added, which, with the prolongation constructed in 1862, forms what is now called the *Quai du Rhin*. In 1853 it was decided to construct outside the fortifications a dock which now forms part of what is called the Kattendyk dock, together with a large dry dock, and a lock of 25 metres width (82 ft.), opening into the Scheldt. These works were finished in 1860; and the fortifications being demolished shortly afterwards, the new dock was connected with the old ones, and three other basins, all of large size, were constructed. These were completed in 1873.

The following, then, was the position of the port of Antwerp at the period when the works which form the subject of the present paper were commenced. There were, first, quay-walls along the river having a total length of about 2100 metres (7000 ft.);

secondly, four old creeks, still opening into the river; thirdly, the old docks of Napoleon, having an area of about 8 hectares (20 acres), connected to the Scheldt on one side and to the new docks on the other; fourthly, the four new docks, with an area of about 30 hectares (75 acres); fifthly, three dry docks for repairs. The total length of the quays within the docks was about 6500 metres (21,300 ft. or 4 miles). Most of these quays and a part of those on the river wall were in connection with railways, and several of them were occupied by sheds. In the last few years the erection of sheds and mechanical appliances has been largely extended. Steam and hydraulic travelling cranes, fixed cranes of great power, hydraulic machinery for working the lock gates and bridges, have been constructed, whilst the quays are connected with immense railway stations, having a total area of 31 hectares (77 acres), and a total length of sidings of 65 kilometres (40 miles); at the same time the docks are in direct communication with the Campine canal connecting the Meuse with the Scheldt.

Nevertheless, despite these large works, and the efforts made to utilise them to the utmost, their insufficiency for the present trade of the port became every day more evident. In addition, the quay walls on the river, constructed bit by bit on very irregular lines, were ill adapted for any important trade. Except on the Quai du Rhin, there were no means of working these river walls by railways, and they could not even be approached at low water, their footings being laid at the low-water level: ships were obliged either to lie on the mud or keep at a distance from the walls. Finally, the irregular form of the quays, a marked projection which occurred about the middle of their length, and the necessity of providing projecting jetties, produced a retardation in the river currents, and in consequence deposits of sand and other inconveniences; whilst the ground available was insufficient for a complete and regular working of the traffic. It was therefore decided to re-construct the whole of the quays upon a regular curve, concave towards the river. This curve is formed of several circular arcs tangential to each other, and has a total length of 3500 metres (11,500 feet or 2·2 miles). At the same time the creeks which divided the then existing quays

were to be replaced by large floating basins for smaller vessels. The docks being also insufficient, it was resolved to lengthen one of them, and to add three new dry docks to the three already existing. The new quays are being executed by the State, but will be furnished with the necessary appliances at the cost of the town: the other works on the docks are being executed by the town alone. The portion to be provided by the State was contracted for in 1877 by Messrs. Couvreux and Hersent of Paris, and comprised the following works.

First, the construction of a quay wall 3500 metres long (2·2 miles), resting on a sound foundation, laid without any timber footings, and giving a depth of not less than 8 metres of water (26¼ ft.) against the face at low tide (Fig. 2, Plate 51). In this wall are three recesses, rectangular in plan, which are intended to accommodate floating landing-stages, and give access for boats. The landing-stages will not project beyond the line of the quay, and will be made of iron having a movable platform joined to the wharf by a movable bridge. Two of these landing-stages are 20 metres long by 10 metres wide (66 ft. by 33 ft.); the third is 100 metres by 20 metres (330 ft. by 66 ft.).

Secondly, the building at the south end of this quay wall of an embankment connecting it with the land: this embankment to be 650 metres long (2130 ft.), and to be properly protected against the action of the river.

Thirdly, the construction of a basin for small craft, having an area of about 4 hectares (10 acres), and divided into three parts; a lock 13 metres wide (42 ft.) connecting this basin with the Scheldt; and an entrance channel 50 metres wide (160 ft.).

Fourthly, the filling-in necessary behind the new quay wall, and in the creeks which were to be done away with; as well as the dredging required to maintain the full sectional area for the river throughout the period of executing the works.

The walls of the new quay and of the floating basin are calculated to stand a distributed load of 6 tons per sq. metre (11 cwts. per sq. ft.), the load extending over the top of the wall itself and the quay space behind it.

The works were divided into four sections, the whole to be completed within six years and seven months from the commencement. They included the provision and fixing of twelve million kilogrammes (12,000 tons) of wrought-iron for the caissons in the foundations, the landing-stages, swing-bridges, &c.; 375,000 cubic metres (490,000 c. yards) of brickwork and concrete; 25,000 cubic metres (33,000 c. yards) of masonry in Soignies stone, and more than $2\frac{1}{2}$ million cubic metres (3,300,000 c. yards) of earthwork in filling, dredging, &c. The cost is estimated at more than 38 million francs (£1,520,000); being augmented or diminished, according to an agreed schedule, with any augmentation or diminution in the depth of foundations which may have become advisable. To this will be added about 1,500,000 francs (£60,000) for additions to the foundations. The whole should be completed about the commencement of 1884.

The above sketch is sufficient to show the important character of the works now under construction. The author will now describe briefly the first section of these works (which are constructed in front of the position occupied by the old southern citadel, now demolished), and the methods employed by the contractors in their execution. This section of the works (Fig. 1, Plate 51) includes in the first place the new basins for small craft, which are already completed. They run parallel to the river, and are three in number. The central basin, from which branches the lock connecting them with the Scheldt, is 266·5 metres long and 65 metres wide (874 ft. by 213 ft.); the two others are respectively 246 and 225·5 metres long (807 ft. and 740 ft.), with a width of 50 metres (164 ft.). They are joined to the central basin by openings 10 metres wide (33 ft.), each crossed by a swing-bridge carrying a roadway $5\frac{1}{4}$ metres wide ($17\frac{1}{4}$ ft.), and two footways, each of 1 metre ($3\frac{1}{4}$ ft.). The bottom of the basins is 2 metres ($6\frac{1}{2}$ ft.) below the level of low water at Antwerp; and the coping of the walls 6·35 metres (21 ft.) above the same level. The total length of these walls is about 1800 metres (5900 ft. or $1\frac{1}{8}$ mile). They rest at the bottom level on a layer of concrete 1 metre thick and 5 metres wide ($3\frac{1}{4}$ ft. and $16\frac{1}{2}$ ft.), enclosed by two rows of sheet piling. The wall, built of Boom bricks, is 8·35 metres high (27·4 ft.), including the coping; 4 metres

wide at the base, and 2½ metres at the top (13·1 ft. and 8·2 ft.). The wall has a batter of 1 in 10, and is faced with hammer-dressed stone from the coping to a height of 2½ metres (8·2 ft.) above low water. The quay space of these basins has a width of 30 metres (98 ft.); it has been paved and has still to receive the necessary appliances for working. The walls are furnished with cast-iron mooring posts, with cast-iron fenders, and with wrought-iron ladders. The basins are kept filled to a level of about 3·60 metres above low water (12 ft.).

The lock between the central basin and the Scheldt has been built partly in the river and partly on dry ground. It is composed of three distinct portions. First, there is the upper lock, with a sill of masonry 0·30 metre (1 ft.) above the bottom of the basin, and resting on a foundation of concrete 2½ metres (8·2 ft.) thick. It has a width of 13 metres (42½ ft.) between the side walls, and is crossed by a swing-bridge 8½ metres wide (28 ft.), intended not only for horse traffic but for the railway which will serve the quays on the Scheldt. This lock was constructed between two rows of sheet-piling, and behind an earthen cofferdam connected at each end with the original banks of the river. It has a pair of gates opening inwards, and is arranged for receiving, if necessary, another pair opening outwards. Secondly, there is the lock chamber, 75 metres long by 25 metres wide (246 ft. by 82 ft.). Its walls are similar to those of the basins, but they are entirely faced with ashlar. The invert rests on a layer of concrete 1 metre thick (3·28 ft.), and its surface is 2 metres below low water (6·56 ft.). The whole is surrounded by sheet-piling. Thirdly, there is the lower lock, which contains two pairs of gates, and has its invert level the same as that of the chamber. The side walls are 13 metres apart (42½ ft.), and are crossed by a swing-bridge of the same dimensions as that across the upper lock, and carrying a roadway and two lines of railway.

The chamber and lower lock had to be constructed almost entirely within the area of the Scheldt. Instead of building a cofferdam in the river, so as to proceed with both at the same time, the contractors proposed to make the lower lock itself form part of the cofferdam which should shut in the lock chamber to be built behind it. With

2 P

this object they constructed the whole of the lower lock *in situ*, and in one piece, upon an immense caisson sunk by means of compressed air to a depth of 6½ metres (21 ft.) below low-water level. This caisson was 40 by 23 metres (131 ft. by 75½ ft.), having an area of 920 sq. metres (9890 sq. ft.). Its total height was 13 metres (42½ ft.), giving a content of 11,960 cubic metres (420,000 c. ft.). Inside the roof it was divided longitudinally into five working chambers completely independent of one another, each having its own air-lock and tubes for concrete. The walls of the caisson were joined near the top and above the girders by cross-girders of iron. The caisson was erected on the banks of the Scheldt in a spot sheltered from the tide by an earthen embankment. When complete, the embankment was cut through on the side near the river, and the tide entering floated off the caisson, which was then towed without any damage to its proper position. The sinking was commenced in August 1878, and was finished by November of the same year. The masonry having been carried up a certain distance, it was then connected with the bank at either end by an earthen embankment. A vast basin was thus formed, which needed only to be pumped dry in order to commence the foundations of the lock chamber. When the chamber and locks were completed, all that remained was to remove the iron barrier across the end of the lower lock next the river, by cutting the rivets and unbolting the wrought-iron knees which supported it.

The six gates belonging to the entire lock are all of wrought-iron, and made without rollers; the lowering of the water is effected by means of sluices in the side-walls, and valves in the gates themselves. Between the lower lock and the line of the new quay is an entrance channel 50 metres long (164 ft.) and the same in width, intended to shelter boats from the river current as they enter or leave the lock. The bottom of this channel is 2½ metres (8 ft.) below low-water; its walls were built upon caissons sunk by compressed air to depths varying from 10·5 to 12·6 metres below low water (34½ ft. to 41½ ft.), and in the manner to be described hereafter.

The embankment connecting the southern end of the new quay-wall with the banks of the Scheldt was finished in 1878. It is

650 metres in length (2130 ft. or 0·4 mile), and is founded partly on rubble, partly on platforms of fascines loaded with stone; and stone is thrown in at the greater depths to form a sound footing for the embankment. This is constructed of an argillaceous alluvial earth called "schorre," and of sand dredged from the Scheldt; the river slope is paved with rough-hewn stone.

The new quays have now been constructed for a considerable distance both above and below the entrance to the basins already described. The filling in behind the walls has been performed partly by hopper barges discharging spoil dredged from the river, partly by locomotives bringing earth removed from the basins, and from lands acquired outside the works. The extent of this work may be judged from the fact that the quay head of the entrance channel to the basins is more than 150 metres (500 ft.) in front of the old dyke which formed the border of the river, and that two-thirds of the ground between the basins and the new quay wall has been won from the river-bed. Behind the basins extends the new southern quarter, occupying the site of the ancient Spanish citadel, and bought in 1874 by the Société Anonyme du Sud d'Anvers. It is intersected by wide streets, and is being covered with new buildings. Altogether it has an area of 115 hectares (284 acres); and to the south of it, close to the new fortifications, is the southern railway station, having an area of 20 hectares (50 acres), and specially intended for the service of the new quays. At some future date it is probable that this station may be made to communicate with the left or western bank of the Scheldt by a bridge carrying a roadway and one or two lines of railway, which would be constructed by the State. Immediately above, or south of this bridge, in the corner between the railway and the fortifications, the town intend to construct a small basin, dry at low water, and especially intended for barges carrying materials for construction. It will be 115 metres by 50 metres (377 ft. by 164 ft.), having a length of 340 metres of quay wall (1115 ft. or 0·21 mile), and will be surrounded by a roadway 30 metres wide (100 ft.). Its entrance will be crossed by a swing-bridge.

From the northern side of this entrance begins the quay wall,

built within the bed of the river, and extending from thence in one curve to the old docks. This wall, Fig. 2, Plate 51, has been built by a special system of movable cofferdams which will be described immediately. It is constructed of Boom bricks, and faced with Soignies stone; the coping level is 6·35 metres (21 ft.) above low water; the total height is 14·35 metres (47 ft.), and the width is 2 metres at the top (6·56 ft.), 6·25 metres at low-water level (20½ ft.), and 7 metres at the base (23 ft.). It has a batter of 1 in 20 from the coping to low-water level, and 1 in 10 from thence to the foundations. The upper part of these foundations is throughout at a level of 8 metres (26¼ ft.) below low water, and has a breadth of 9 metres (29½ ft.); the depth varies between 2·50 and 5 metres (8¼ and 16½ ft.), according to the depth of the river-bed and the nature of the soil, so that the bottom of the foundation is from 10·50 to 13 metres (34½ to 42¾ ft.) below low water.

The difficulty of carrying out such works in the Scheldt is very great; the sandy and shifting nature of the bottom, the speed of the current, and the great rise of tide, are all adverse circumstances. It was required to build a continuous quay wall with its foundations 34 to 43 ft. below the low-water level of a rapid river, rising twice in the day to more than 13 ft. on the average above this level, and sometimes at high tides to 21 ft. The method adopted by the contractors was as follows: they divided the total length of the quays into lengths of 25 metres each (82 ft.), which have been built end to end, and directly upon firm ground, without any intervening substratum. This has been accomplished by means of a special cofferdam used for the first time on this occasion, and with most complete success. It is composed of the following parts.

Firstly, an iron caisson for compressed air AA, Figs. 3 and 4, Plate 52, varying in height according to the depth at which the foundations are to be laid, and intended for removing the soil and laying the base of the wall.

Secondly, a movable iron cofferdam BB, 12 metres high (40 ft.), having the same shape as the caisson on which it stands, and with which it is connected by bolts. Within this cofferdam can be built, in the dry and in the open air, the part of the quay wall, 8 metres in

height ($26\frac{1}{4}$ ft.), which is comprised between the top of the foundations properly so called and the level of low water.

Thirdly, a floating framework CC, designed for the manipulation of the cofferdam and for the placing and sinking of the caisson.

The caisson serves for the removal of the earth, and is then filled with concrete and becomes an integral part of the foundations. The masonry having been built on the top of this up to low-water level under the shelter of the movable cofferdam, it becomes possible to remove the cofferdam by unbolting it from the caisson and raising it by chains fixed to the floating framework. It is then taken away to serve the same purpose for another length of wall, while the length so far constructed by its means is finished in the dry.

Such is the general plan of operations; a few details are subjoined.

The caissons AA have a uniform width of 9 metres ($29\frac{1}{2}$ ft.) and a length of 25 metres (82 ft.) Their height varies from 2·60 to 5 metres ($8\frac{1}{2}$ to $16\frac{1}{2}$ ft.), according to the depth required, the footings of the wall, properly so called, being, as already stated, always at a depth of 8 metres ($26\frac{1}{4}$ ft.) below low water. Each caisson has vertical sides of plate-iron, riveted to longitudinal and transverse angle-irons. It is divided into an upper and a lower portion by a horizontal partition D; the lower portion forms the working chamber, and has a uniform height of 1·90 metres ($6\frac{1}{4}$ ft.) from the lower edge to the roof. This roof is riveted to a series of transverse lattice-girders EE, strong enough to support the load of masonry to be built upon the caisson, and at the same time to prevent any buckling of the sides. An angle-iron is riveted all round the external edge of the top of the caisson, and through this pass the bolts which connect it to the cofferdam. The roof of the caisson has five circular openings, in which are fixed wrought-iron tubes. Four of these F are 0·50 metre in diameter (1·14 ft.), and are intended for the concrete, whilst the fifth G, which is in the centre, has a double air-lock for the workmen and for compressed air. The masonry is so built as to leave round each of these tubes an annular space, so that they may be unbolted and withdrawn when the sinking is completed; the spaces are afterwards filled with concrete.

The caissons are built in yards on the bank of the river, and are

launched at high water; they are then towed to their destination underneath the movable cofferdam, and are bolted to the latter, a layer of india-rubber being placed between the two. The weight of a caisson 82 ft. by 29½ ft. varies from 65 to 100 tons, according as the height is 8¼ or 16½ ft.

The movable cofferdam BB is composed of a large wrought-iron rectangular box, 25 metres by 9 metres (82 by 29½ ft.), and 12 metres (40 ft.) high. This height is sufficient to protect the interior against ordinary tides, which at Antwerp have a rise of 4·05 metres (13¼ ft.). The sides have a thickness varying from 7 mm. at the top to 12 mm. at the bottom (0·28 to 0·47 in.), and are stiffened externally by rolled girders and diagonals. Round the lower edge of the box runs a wrought-iron rectangular tube H, 1·50 metre high and 0·50 metre wide (4·92 and 1·64 ft.), through which a man can pass to bolt or unbolt the joint between the caisson and the cofferdam. There are four manhole tubes, 1 metre by 0·50 metre (3·28 by 1·64 ft.), through any of which the workman can enter: when within he is then protected by means of compressed air. These tubes are riveted to the outside of the cofferdam, stiffened by gussets, and furnished with air-locks. The upper part of the cofferdam is stiffened by strong lattice girders inside, and the lower part by being bolted to the caisson. Valves are placed at the ends for letting water in when required, in order to increase the load on the caisson, and thus facilitate its sinking. To prevent any deformation of the walls of the cofferdam under the pressure of the water, whilst the building of the masonry is going on inside, they are connected with each other by strong movable stays, which as the work proceeds are removed, and replaced by shorter stays bearing against the face of the wall already constructed. The cofferdam complete with all its apparatus weighs about 200 tons.

The floating framework CC is composed of two iron barges, 26 metres by 5 metres (85 ft. by 16 ft.): on these are built frames of iron JJ braced diagonally, and connected at a height of 13 metres (43 ft.) above water-level by cross-girders; they are also connected by a similar framework at the two ends. The cofferdam is suspended by twelve chains in the space between the two barges, and

can thus be raised or lowered at will by means of hoisting gear, consisting of six winches in each barge, all twelve worked by one steam-engine. The power is transmitted from one barge to the other by means of two pitch-chains. Uniformity of lifting with the twelve lifting chains is secured by india-rubber springs; each tackle has a lifting power of about 20 tons. In the hold of the barges are the steam-engine for working the cofferdam, the air-compressors, the pressure pumps, and the exhausting pumps. On deck are mortar-mixing machines, and other machines for handling the materials. Four Jablochkoff electric lamps are placed on each framework for working by night. The two barges, with their framework, engines, boilers, etc., weigh altogether about 300 tons.

The method of working with this apparatus is as follows. The site for the caisson is first dredged to the proper level: the caisson is then brought up to the floating framework, and its roof is loaded to the top of the girders with concrete, which ultimately forms part of the foundation. The cofferdam is lifted until its bottom edge is about 1 metre (3·28 ft.) above water-level, and the caisson is then brought in under it; the cofferdam is lowered upon it, and the two are bolted together. The masonry is then commenced on the top of the caisson, so as to load it with the necessary weight, whilst at the same time the air-tube G and the four concrete-tubes FF are attached to it. When the weight of masonry is sufficient to bring the lower edge of the caisson almost down to the river bottom at low water, the whole structure, which weighs about 2000 tons, is brought into the exact line of the quays and firmly moored. The masonry is then continued within the cofferdam, whilst at the same time the working chamber at the bottom of the caisson is filled with compressed air; and as soon as the caisson rests on the ground, with weight sufficient to resist the upward pressure, water is admitted inside the cofferdam so as to increase the weight bearing upon the caisson. The workmen then enter the working-chamber and excavate the soil; as they do so, the caisson sinks gradually until it reaches a firm foundation at the desired depth.

The bottom of the Scheldt is generally composed of sand, more or less argillaceous, and of loamy earth. Under these circumstances the

work of removing the earth excavated has been considerably facilitated by the use of ejecting apparatus, as first employed by the same contractors at Selzaete Bridge on the Terneuzen Canal. For this purpose the earth is shovelled into an iron box fixed to the roof of the caisson; a tube furnished with a stop-cock leads from this box to the exterior of the caisson, whilst a second tube opening into the box brings in water under a sufficient head to overcome the pressure of the compressed air. This water reduces the earth in the box to slush, the action being quickened if necessary by stirrers actuated by hand-power. When the mixture is complete, the opening of the stop-cock allows the compressed air to act and to expel the slush through the tube to the outside of the caisson. Each ejector can easily discharge 2 cubic metres (2·6 cub. yds.) of earth per hour. When the excavation is finished, the working chamber is filled with concrete in regular layers through the four tubes previously mentioned. During the whole of this time the further loading of the cofferdam is continued, with a sufficient quantity of materials to balance the increasing displacement caused by the sinking of the mass, and by the injection of the compressed air. When the working chamber is completely filled with concrete, the concrete-tubes and air-tube are removed, the water is pumped from the inside of the cofferdam, and the masonry is then continued up to a height of about 0·50 metre (1·64 ft.) above low water. The cofferdam is then unbolted by means of workmen entering through the tube H previously described, which is filled with compressed air. The cofferdam is then lifted by means of the winches, and taken away to another caisson for a similar operation.

It follows from this method that almost the whole of the masonry below water is built in the open air, the filling of the working chamber being all that is done under compressed air. The superintendence of the working is therefore easy, and the construction cheap. In addition to the economy thus obtained in the masonry, this method presents also the great advantage of almost entirely avoiding the loss of the iron plates, which in the older systems were riveted to the caisson as it descended, and were withdrawn as best they could be after the completion of the masonry. A single cofferdam

now serves for any number of caissons. At first the putting in of the foundation for one 25-metre length of wall (82 ft.), and the raising of the masonry to low-water level, occupied thirty-five to forty days; the time has now been reduced to about twenty-five days.

The interposition of the sides of the cofferdam leaves of course an interval, of about 1 metre ($3\frac{1}{4}$ ft.), between the successive lengths of wall. The sides of this gap are temporarily closed by wooden sheeting, and the gap is then filled in with concrete thrown down under water up to the height of low water. Vertical grooves are left in the ends of the adjacent lengths of walling, and are filled in with concrete, which thus forms a sort of joggle between the two lengths of wall. Above low water the masonry is carried up by tidal work in continuous courses.

The arrangements for working the new quays, and for connecting them with the existing lines of railway, may be described as follows.

Throughout the whole length of the new quays there will be two main lines of railway, separated by an iron railing from the street of 20 metres width which extends along the front of the houses. Running parallel to and connected by switches with these main lines there will be three other roads—one for wagons arriving loaded, the second for wagons arriving empty, and the third, covered by the sheds, for the operations of loading and unloading. Along the quay itself will run a sixth road, united to the main line by transverse roads passing between the various sheds, and intended for the transference of merchandise direct from vessels on to wagons. Over-head movable hydraulic cranes will run on a special way laid outside this road. Between the fourth line of rails and the quay will be built iron sheds, occupying a total width of about 50 metres (160 ft.). These lines and sheds have already been completed for a length of about 1400 metres (4600 ft.) of the quay. The sheds when complete will cover an area of about 100,000 square metres (1,076,000 sq. ft. or 25 acres). The total width of the new quays is 100 metres (328 ft.). To obtain this width it has been necessary to pull down more than 600 houses, the purchase of which has cost more than 25,000,000 francs (£1,000,000). The total cost of the

quays, including masonry, earthwork, dredging, paving, works above ground, and property purchased, will be about 80,000,000 francs (£3,200,000).

The new quays will be worked by hydraulic machinery. For this purpose steam pumping engines of 400 horse-power have been placed in a building near the southern basin for small craft. From this building a line of pipes is already laid, passing round the small-craft basin and along the first section of the quays. This first section is worked by 22 portable hydraulic cranes. Hydraulic capstans will be used to haul the wagons and cranes along the quays.

It remains to mention the works at the other or northern end of the quay, towards the old docks, Fig. 1, Plate 51. Following the line of the new river-wall, the visitor passes one of the recesses previously mentioned, in which is placed a landing-stage, 20 metres by 10 metres (66 ft. by 33 ft.), provided with a flying bridge, and intended for passengers and goods arriving from the Pays de Waes Railway Station on the other side of the Scheldt. He also passes the entrance of the old docks and the Quai du Rhin, and then has on his right the Kattendyk basin. Here are three dry docks previously constructed, and three which have been constructed during the progress of the present works. These new docks are 133 metres long (436 ft.) with entrances 15 metres wide (50 ft.), and are faced throughout with hewn stone. The gate-chambers are each founded on 280 piles, about 6 metres (20 ft.) long, covered with a gridiron of timber. Sunken cofferdams of sheet piling filled with concrete prevent the passage of any water under the gates. The walls of the dock are founded on the ground, within a casing of sheet piling; they rest on a layer of concrete, 0·80 metre thick ($2\frac{1}{2}$ ft.), and all are of brick faced with stone. Throughout the length intended to receive vessels the bottom has an invert of masonry strong enough to resist the pressure of the water when the dock is empty. At the same time this invert has been filled up with masonry, so as to give the bottom of the dock a slope from the middle towards the sides, thus preventing the rain-water from settling in the middle under the vessel's keel. The steps are wider than in the old dry docks, which assists the workmen in placing the shores,

and also gives the dock greater width; at the same time the coping is brought down almost to the level of the water in the dock outside, so that the depth of the dry dock is as small as possible, and thus gives more air and light round the vessel docked. The keel-blocks, instead of being of wood as usual, are all of cast-iron, each in three pieces. Of these the lowest is fixed into the floor of the dock, the uppermost carries the vessel's keel, and the intermediate piece, which is wedge-shaped, is driven in between the two others, so as to support the keel firmly at all points. The construction of these three new dry docks has required 28,700 cub. m. (37,540 cub. yds.) of brickwork and nearly 5000 cub. m. (6540 cub. yds.) of hewn stone, while more than 100,000 cub. m. (130,800 cub. yds.) have been excavated.

The large dry dock previously existing is emptied by means of pumps capable of drawing 200,000 litres (7000 cub. ft. or 44,000 gals.) per minute. It was desired to make the same pumping engine serve for the new dry docks, but there was great difficulty in doing so, from the fact that the conduit leading the water from the new docks to the engine was obliged to pass below the existing docks. For this purpose a tunnel, about 90 metres long (300 ft.), was driven, and lined with cast-iron tubbing. A well was first sunk by means of compressed air, and the driving of the tunnel was carried on by the same means, the successive lengths of cast-iron tubbing being bolted on to one another, and the water kept back by the pressure of the air. This operation succeeded perfectly, and the extremity of the tunnel has been united with the head of each of the dry docks.

Beyond the dry docks the Kattendyk Basin has been extended so as to give it a total length of about 1 kilometre (32,800 ft.), communicating by one entrance with the old docks, and by another entrance direct with the Scheldt.

The northern docks just described are also worked by hydraulic machinery. A special building contains a 150 H.P. steam pumping engine and boilers, and two accumulators weighing 120 tons each. This engine supplies a water-pressure of 700 lbs. per sq. in. to the movable and other cranes round the docks, the bridge and gate machinery and capstans for hauling ships &c., and also the hydraulic

engines which drive the dynamo-electric machines for lighting the entrance of the old docks.

Among the machines worked by this pressure-water may be mentioned a 40-ton crane altered to the hydraulic system, and a sheer legs capable of lifting 120 tons. These are on the eastern wall of the Kattendyk basin. The lock of this basin is crossed by a draw-bridge having a length of 48·36 metres (158 ft.) carrying a roadway 90 feet wide, and weighing 375,000 kilograms (370 tons). In order to open this bridge it is raised 1 metre (3·28 ft.) by means of two hydraulic rams 0·80 metre in diameter (31·5 in.), and is then drawn forward by chains which are worked by rams 0·61 metre in diameter (24 in.); the bridge can be completely opened in three minutes twenty seconds, and closed in two minutes ten seconds.

Besides these great works for the enlarging of the quays on the Scheldt, extensions and improvements of the docks are also in progress, as mentioned above. The city has issued forms of tender for an extension of the docks towards the north, reaching as far as the northern citadel, which they have purchased. These works comprise the making of two new docks, having a quay length of 3700 metres (12,136 ft. or 2·3 miles) an area of 21 hectares (50 acres) and a depth of 9 metres (30 ft.). These works will cost, including acquisition of property, nearly 20,000,000 francs (£800,000), and are to be completed in three years. Thus from 1877, when the present works were begun, to the date when they will be completed, say 1887, the kingdom of Belgium and the city of Antwerp will have executed maritime works, and acquired property for the purpose, costing a total sum of 100,000,000 francs (£4,000,000) irrespective of improvements made in the works previously existing.

EXCURSIONS.

The Excursions commenced on the afternoon of TUESDAY, 24th July, which was occupied in a visit to the works of the Society Cockerill, at Seraing. For a description of the works see below, p. 519. The members travelled in three parties, the first by steam tram to Seraing bridge, the second by train to Seraing station, and the third by steamer on the Meuse. This last party lunched on board the steamer, and the first two were successively entertained in the great hall of the chateau; the whole being by invitation of M. E. Sadoine, managing director. The following address was delivered in English by M. Sadoine, to the members of the first of these groups:—

GENTLEMEN,

On seeing before me so large a number of distinguished members of a friendly nation, I am reminded of the numerous ties that unite our respective countries; and my first impulse was to propose the healths of the two sovereigns who so happily direct our destinies. On second thoughts however, I reflected that we do not here tread on political ground, and that this assemblage has no official character.

I will therefore simply state that I am proud to see the Council of the Institution of Mechanical Engineers of England choosing Belgium this year as the place of their annual meeting. Here we have a new proof of those friendly bonds that unite us to Great Britain. I consider the choice made of Liége as a most happy one. In no other town are the interests of industry and science nearer to the hearts of the inhabitants.

We are not unmindful, gentlemen, of all that we, as a manufacturing and commercial nation, owe to England. May we not flatter ourselves that our own efforts in the same direction have had an echo across the channel, and that we may all be said to have contributed to the great work of progress and civilisation going on in the world?

In making you welcome, gentlemen, to the works founded by the illustrious John Cockerill, I am happy to have the honour of proposing your healths, and I drink to our still closer union under the glorious banner of science and industry.

The following address was also delivered by M. Sadoine, to the members of the second group :—

Gentlemen,

It is a great pleasure to me to offer you a welcome to Seraing. It is also a great honour to show to the sons of Old England the Works founded by one of their predecessors sixty years ago—works which the successors of John Cockerill have left and will leave under the shadow of that illustrious name. The name of Cockerill represents a tradition of science, of search after progress, of persevering work, of courage and energy in days of difficulty.

To remain faithful to the glorious traditions of the creator of Seraing, to develop continuously the great plant of this establishment, while watching over the welfare, the education, the morals of our excellent working population, is for us a duty. We shall not fail, for we have, to sustain us in our efforts, the motto of our great founder: "Courage to the last."

In again bidding you welcome, I trust, gentlemen, you may be able to see whether we have fulfilled that duty or not.

After inspecting the works, the members returned by steamer from Seraing Bridge. The steamers were supplied free by the kindness of M. Ernest Orban; as was also the train by the kindness of the Northern Railway of France, and the steam trams by the kindness of M. Dupont.

In the evening the summer Dinner of the Institution took place in the Salle de la Légià, Liége, the President in the chair; and was largely attended, a number of distinguished Belgians being present as guests.

On the afternoon of Wednesday, 25th July, three alternative Excursions took place. The first of these was to the Engine Works of the Ateliers de la Meuse (see below, p. 534), the Sclessin Iron Works (see below, p. 535), and the Horloz Collieries (see below, p. 530). The excursion was made by steam tram, provided free by the kindness of M. Dupont. At the Ateliers de la Meuse the party were received by M. Stévart, managing director; at Sclessin by M. Dallemagne, managing director; and at Horloz by M. Charlier and M. Braconnier.

The second Excursion was to the Angleur Steel Works (see below, p. 537); the Ougrée Blast-Furnaces and Collieries (see below, p. 538); and the Ougrée Iron and Steel Works (see below, p. 541). The trip was taken in a steamer on the Meuse, provided free by the kindness of M. Orban. At Angleur the members were welcomed by M. Galler, in the unavoidable absence of M. Rossius, managing director, and had the opportunity of seeing in successful operation the Thomas-Gilchrist or Basic process for the manufacture of steel. At the Ougrée Blast-Furnaces the members were received by M. L. Cheneux, managing director; and at the Ougrée Iron and Steel Works by M. A. Raze, managing director.

The third Excursion was to the Marihaye Collieries (see below, p. 530), and to the Val St. Lambert Glass Works (see below, p. 544). The excursion was by special train, provided free by the kindness of the Northern Railway of France. The members were received at Marihaye by the managing director, M. Dubois; and at Val St. Lambert by M. Jules Deprez, managing director.

Thursday, 26th July, was devoted to two alternative Excursions; the one to the works of the Vieille Montagne Zinc Mining Company at Chênée (see above, p. 319), and to the Hasard Collieries (see below, p. 531); and the other to the Woollen Manufactories of Verviers (see below, p. 546).

The Excursion to Chênée was by ordinary train. The members were accompanied by M. Trasenster, and were received by M. St.

Paul de Sinçay, managing director, by M. Vapart, and by the staff of the establishment. They were conducted through the works in groups, and were afterwards entertained at luncheon, when the following speech was delivered by M. St. Paul de Sinçay :—

"GENTLEMEN,

"If I considered your presence here as a mere visit of curiosity, I should content myself with thanking you for the honour you have done us; but in this flattering manifestation of interest in Belgium, on the part of the *élite* of British engineers, I see a fact of more importance than a simple tourists' excursion; and I ask your permission to explain my meaning further. It appears to me, gentlemen, that your visit expresses a need which is felt, but has only lately been felt, by civilised nations—the need to see each other, to know each other better, to dissipate prejudice and error (those everlasting sources of division), to seek in a better appreciation of common interests, and in a more exact knowledge of facts, the true ground for mutual peace among the nations of the earth. Who could have predicted fifty years ago that two hundred leading engineers of the United Kingdom, representing one of the principal branches of British industry, would descend upon our soil as friends, and by their presence give a brilliant confirmation to the doctrine that the material interests of civilised nations are one?

"In former days manufacturers did not thus visit each other; or if they did they came in a totally different manner. They did not appear as friends to exchange ideas with one another; such visits as were paid were visits of war.

"A great change has now taken place; the brilliant discoveries which will make these ages famous for ever, such as the discovery of steam power and of electricity, have transformed men as they have transformed things. Fifty years ago, gentlemen, you would not have come, and I am not sure whether we should have received you; but to-day it is with the greatest pleasure we open our gates as wide as possible; we look on you not as enemies but as brothers in arms, fighting the same battle, and content that in this pacific

struggle the advantage should remain with the most energetic, the most worthy.

"England has been our great instructress in industrial matters, and especially in that queen of industries, the iron and steel trade; and we hope that the visit with which you have honoured us will leave in your minds the impression that Belgium, the pupil of your great country, has profited by the lessons she has received. Possibly you will find with us some things that are interesting and useful, some things which you may even be glad to learn. In that case all that we desire is that you should carry back to your great country the recollection of our cordial esteem, and of the pleasure it gives us to receive you. I ask you to drink to the union of the English and Belgian industries, a union of which your visit is the symbol and the witness."

From Chênée a special train, provided free by the kindness of M. Jules d'Andrimont, took the members in the afternoon to the Bay Bonnet tunnel, where they were received by M. d'Andrimont, managing director of the Hasard Collieries, and where they visited the fuel works, coal-washing appliances, &c. From thence they walked to the workmen's town near Micheroux, which they inspected, and were afterwards entertained at a collation by M. d'Andrimont. They then returned by special train to Liége, and from thence proceeded by special train to Antwerp.

The Excursion to Verviers was by ordinary train. The members were received at the Verviers railway station by M. Mullendorff, President of the Chamber of Commerce, and by several other gentlemen of the town. M. Mullendorff welcomed the members, observing that Verviers possessed but one manufacture, that of wool, but that this could be seen in all its details. The party then proceeded to visit the Wool-Washing Works of M. Eugène Mélen, where they were received by the proprietor; the La Vesdre Wool-combing and Spinning Works, where they were received by the managing director, M. Math. Drèze-Rick; the Wool-spinning Works of M. Hauzeur-Gérard fils, where they were received by the proprietor;

the Woollen Cloth Manufactory of MM. Peltzer et fils, where they were received by MM. Édouard and Augustus Peltzer; and the Wool-card Manufactory of M. Duesberg-Delrez, where they were received by the proprietor. (The above works are described below, see p. 546). They were subsequently entertained at luncheon by kind invitation of the Chamber of Commerce (President, M. Mullendorff; Secretary, M. Dückerts), at the hall of the Société de l'Harmonie. In the afternoon they drove in private carriages, kindly lent by gentlemen of the neighbourhood, to the Reservoir of La Gileppe (see below, p. 553), taking at first the route by Stembert (see Map of District, Plate 29), but returning by Limbourg and the Valley of the Vesdre. They then returned from Verviers by ordinary train to Liége, in time for the special train in the evening for Antwerp.

On FRIDAY, 27th July, the members left the Town Hall, Antwerp, immediately after the reading of M. Royers' paper (p. 494), on a visit to the Docks, Fig. 1, Plate 51. They passed round the Great Basin, and inspected the working of the hydraulic machinery in the goods shed at its head. They then walked to the Kattendyk Basin, inspected the hydraulic engine-house, 120-ton sheers &c., and were conveyed by steamer across the basin to the new dry docks. They then witnessed the working of the great hydraulic drawbridge across the main entrance, and inspected the large pumping engines used for draining the dry docks. They next embarked on board the steamer "Télégraphe," which took them up the Scheldt to the Society Cockerill's dock-yard at Hoboken. Here they were received by M. Sadoine, junior, and saw two vessels on the stocks, both being built for the company, and also inspected the machine-shops and tools. Returning to the steamer, they were conveyed down the river to the yard belonging to Messrs. Couvreux and Hersent, contractors for the new quays. They were admitted under one of the great caissons, which had just been finished, and were there most hospitably welcomed by M. Hersent. The members then inspected the new hydraulic pumping station for the moving cranes, capstans, &c., on the new quays. These have compound

horizontal pumping engines of 400 horse-power, fed by tubular boilers, under construction from the designs of M. Matthys. The members then returned to the steamer, in order to go on board the movable cofferdam, which was engaged in setting one of the lengths of the new quay wall, as described above (see pp. 502–7). They then landed finally, and divided into several parties in order to inspect the Musée Plantin (which was kindly kept open for the purpose), and the Diamond-Cutting Works of M. Jean Coetermans and of MM. Kryn-Huybrechts et fils. In the evening the rooms and grounds of the Cercle Artistique et Scientifique were thrown open to the members. (For notes on the trade of Antwerp see below, p. 557).

On Saturday, 28th July, alternative Excursions took place to Ghent, and to the Collieries of Mariemont. The members travelled to Ghent by special train, and were received at the Sud station by M. Braun, M. Henri de Brouckere, M. Galland, and others. Here they were divided into three parties. The first of these visited the Cotton Spinning and Weaving Works of the Société Ferdinand Lousbergs, M. Joseph de Hemptinne managing director. The second visited the Flax and Tow Mills of the Société La Liève, managing director M. Louis Desmet; and the third the Cotton Spinning Works of M. Jules de Hemptinne. The two latter sections then united, and proceeded to inspect the new Quay Wall, &c., at the Avant Port, under the direction of M. Deheem and M. Vanderlinden. The three sections afterwards united, and lunched at the Nursery Gardens of M. L. Van Houtte; after which they walked along the docks, examining the machinery and entrepôts, to the Locomotive Works of Messrs. Carels frères. (For notices of the above Works see below, p. 564).

In the other Excursion the members travelled by train to Mariemont, where, in the absence through illness of M. Guinotte, general manager, they were received by MM. Jean and Pierre Van Volxen, M. Briart, M. E. Peny, and others. They inspected the St. Arthur pit, and then walked to the Triage Centrale, or Central Screening Station, the arrangements of which were inspected.

Afterwards they were entertained at luncheon by the Mariemont and Bascoup Companies, M. P. Van Volxen presiding. Among others present were M. Guibal, inventor of the Guibal fan, and M. Coppée, inventor of the Coppée coke ovens and coal-washing apparatus. In the afternoon the members visited No. 5 pit of the Bascoup collieries, the largest and best equipped in the district; and then left by special train from Bascoup station to Manage, where they dispersed. (For description of the Collieries see below, p. 570.)

DESCRIPTION OF THE WORKS OF THE SOCIETY COCKERILL.

Abridged from a notice prepared expressly for the Meeting, under the superintendence of M. E. SADOINE, Managing Director.

I.—History.

Seraing is situated on the river Meuse, about six miles above Liége. It lies on the carboniferous formation, which enters Belgium by Hainault, traverses it from west to east, and leaves the Belgian frontier by Henri-Chapelle and Welkenraedt. This formation, lying from Charleroi to Namur in the valley of the Sambre, and from Namur to Liége in the valley of the Meuse, thins out in the latter district: the carboniferous limestone follows the left bank of the river as far as Flémalle; then dipping suddenly, throws up the coal-seams on the right bank more numerous, thicker, and richer than before. These beds underlie the whole of Seraing, where they were discovered about 1190.

At an unknown date the Princes of Liége built their summer palace at Seraing. It fell to ruins in the time of George Louis de Berg (1724), who restored, embellished, and enlarged it. It became national property when the Belgians passed under French domination, served as a military hospital, and was then transformed into a powder magazine. In 1815, on the foundation of the kingdom of the Netherlands, the palace and its dependencies remained the property of the Public Domain; which latter ceded it two years afterwards to James and John Cockerill, for the establishment of workshops for the manufacture of machinery, and for flax-spinning by the processes which they were then introducing into the country.

The establishment of Seraing was the development of the work done by Cockerill the father, at the Jesuits Bridge at Liége, from 1802 to 1813, and by James and John Cockerill after that date. The workshops at Liége had carried out work of immense magnitude

for those days, consisting chiefly of machinery for spinning wool and flax and for the operations of weaving.

Between 1818, the date of beginning work at Seraing, and 1823, when John Cockerill fixed his residence there, forty-three steam-engines had been made. They consisted of motors for spinning-mills, and of winding and pumping engines for collieries.

From 1824 down to the Belgian revolution in 1830, the number of steam-engines constructed amounted to 158, among them being one of 230 nominal HP. for the Royal Dutch corvette "Atlas." The circle of operations had extended. Blowing machinery, motors for iron-works, steam corn-mills, and especially marine engines, furnished the principal contingents.

The Belgian revolution of 1830 completely stopped this forward movement, by closing to the Belgian works the outlet of Holland.

From 1833 to 1835, quiet being re-established, 53 engines were turned out, of which two were for pumping (100 and 200 HP. respectively), and two were for boats (70 and 110 HP.) There were also two steamers. Besides this, the works had built for the Belgian State Railway the first large locomotive constructed on the Continent, and had rolled the rails it was to run on. The creation of railways made up for the outlets closed in 1830.

But the financial crisis of 1840, the death of John Cockerill, and the winding-up which followed, ending in the formation in 1842 of a limited company for the carrying on of the establishments, weighed heavily upon Seraing.

The production of the four years from 1840 to 1843 only rose to the same total as in 1839, that is, 24 stationary engines, 31 locomotives, 3 marine engines, and 3 steamboats; 1844 gave 12 stationary engines, 10 locomotives, 1 marine engine, and 1 steamboat.

In 1845 the movement was more considerable, and steady progress was made henceforward. In 1849, 1850, and 1851, 13 steamboats, besides 184 engines, left the Cockerill establishments. These engines included those sent to the Great Exhibition of London, which obtained the Grand Medal.

From 1852 to 1857, 236 stationary and marine engines and 150 locomotives left the Cockerill workshops.

From 1857 to 1865, 583 stationary engines, 206 locomotives, and 109 steamboats, among them being two ironclad gunboats for Russia, were produced. The machinery executed during this period comprised the boring machinery for the Mont Cenis Tunnel.

From 1866 to 1883, in its mechanical department, in bridge-building work, in boiler-makers' work independently of engines, and in ships and steamboats, the Society Cockerill has executed 22,670 orders for other countries. This includes seven new mail-boats (1866 to 1870) now running between Dover and Ostend; the first steamer built in Europe on the American system for the Volga; screw cargo-steamers, whose consumption of coal per indicated horse-power per hour is 1·55 lbs.; numerous blowing-engines (Seraing system); the mechanical plant of the steel works at the Ruhr, and at divers Russian works; the steel works of the Compagnie des Forges de Châtillon et Commentry, of the Compagnie du Nord et Est de la France, and those at St. Chamond and at Athus; bridges such as those over the Dniester, the Bug, and the affluents of the Volga; numerous apparatus for air-compressing and for rock-drilling; compound engines, reversing engines, winding and pumping engines; ironclad turrets, steel ordnance, &c.

Since 1866, the establishments of the Société John Cockerill have been managed by M. Eugène Sadoine, administrator-director-general. Under his direction have been carried out the development of the Colard Colliery, the acquisition of two-fifths of the concession of the coal mines of Espérance, and the acquisition of the Somorrostro iron mines in Spain; the creation of a fleet of sea-going steamers for the transport of iron ore by sea, and thence by canal; the blast-furnaces for making pig for the converters, and their connection, on the level of the upper platform, with the Appold coke-ovens at the Colard Colliery, as well as with the depôt for ore on the top of the slag mountain (the latter being in connection, on the one hand with the Namur and Liége Railway, and on the other with the river Meuse, and accessible both ways by locomotives); the creation of a new foundry, of a new steel-rail mill, and of a reversing plate-rolling mill; the construction of the bridge-building shop and its annexes; the creation of the ship-building yard at Hoboken (Antwerp); the

refectories, workmen's houses, hospital, dispensary, and orphanage; the schools for adults and for colliers, the Naval Industrial School at Hoboken, &c.

II.—Description of the Works.

On arrival by rail at the Seraing Station the visitor notices the Colard and Caroline Pits, and the Hospital and Orphanage erected by the Society in a salubrious situation, and surrounded by large gardens. The Hospital can accommodate 250 beds in the case of an epidemic, and all its arrangements are made for that number. In ordinary times forty to fifty wounded or sick patients are under treatment. Those in the employ of the Society, and their families, are admitted free, and those belonging to neighbouring works are admitted on payment.

The Orphanage accommodates 112 pupils of both sexes—children of the Society's workmen. They there receive primary instruction, and lessons in gymnastics and music. At fourteen years of age, the boys are admitted into the works as apprentices, the girls continue as seamstresses or washerwomen as they may be taught.

From the station, the Colard Pit is reached by ascending an inclined plane, at the foot of which, in buildings belonging to the Society, are installed the preparatory classes of the Miners' School, and the school itself. The preparatory classes take children and youths from twelve to sixteen years of age, and the Miners' School is for training head miners, and mining inspectors.

To the east of the inclined plane is a dispensary, belonging to the Society, from whence medicines and necessaries are distributed gratuitously.

Colard Pit.—This contains two shafts of a depth of 530 metres (579 yds.), from which 2000 tons of coal may be raised daily; 5000 cubic metres of water may be pumped out in the same time (1,100,000 gallons).

The winding engine, using a steel-wire rope on a spiraloidal drum, is of more than 1000 HP. net. No other of the kind exists in Belgium.

The two rotary pumping engines, of the type invented in all its

parts by the Society Cockerill, exert 250 HP. each, in water raised, and are similar to those exhibited at the Paris Exhibition in 1878.

The Society's coal is rich, and suitable for the manufacture of coke, and for the requirements of metallurgical establishments. The concession comprises 307 hectares (758½ acres). There are 432 Appolt coke-ovens dependent on these collieries, which produce 360 tons of coke of the best quality per diem. The total coal used in the works is about 1400 tons per diem.

Slag Mountain.—On the inclined plane leading to the pit there is a line of rails 1½ metre gauge, for locomotive and coke wagons; and a double line of narrow gauge, worked by an endless chain coming from the pits, and bringing coal in small trucks for the supply of the furnaces. Towards the middle of the inclined plane in question, is a branch line leading to a number of other inclined planes, arranged spirally around the sloping sides of the artificial mountain, created since 1820 by the continued deposits of shale, slag, scoriæ, and rubbish. They run up to the top of the mountain, which is levelled to form storage-room for the materials (ore, flux, and coke) necessary for the supply of the blast-furnaces.

This mountain, enclosed, so to speak, in the middle of the works, occupied very valuable ground, and its encroachments every year became more and more serious, more especially as the increase of the blast furnaces and steel works required so much more room for the transport and reception of their materials than heretofore.

In 1879 it became necessary to re-arrange communications; and the transformation of the slag mountain, to form a platform for the storage of materials for the blast furnaces, was resolved upon.

It was an important work, as much from the difficulties encountered as from the results to be obtained; the surface occupied by this mountain is considerable, and its height extends 35 metres (115 feet) above the level of the Meuse.

Leaving the aforesaid platform, and following the curves of the railway round the mountain, the Gas Works are passed, where gas is made from the refuse of petroleum,* and then we come to the

* The installation of these gasworks has been of great service to the fitters and workmen employed, the light given by petroleum gas being more brilliant and more steady than that from ordinary coal gas, which tires the sight.

Caroline Pit, with its groups of Coppée coke-ovens, recently acquired by the Society. Further on, and coming to level ground, the road follows the banks of the Meuse through the different stores for steel rails, timber for the pits, iron from the rolling-mills, and especially for the Algerian and Spanish ores, which come from Antwerp by canal. Powerful steam elevators, erected in 1873 on the crest of the river bank, enable the ore to be quickly unloaded. The ore also comes by railway, paying to the State more than a million francs annually for carriage. On arriving at the Seraing railway station, these ore trucks are taken by the Company's locomotives towards the depôt on the top of the slag mountain. If brought by water, the ore is lifted by the elevators and deposited either in iron enclosures stretching alongside the Meuse, or in tip-wagons by which it is taken to the stacks established on the slag mountain.

Nearly in front of the elevators are a third set of coke-ovens (Appolt system), which produce 140 tons of washed coke daily. Close by is the canal, by which barges bring ore, &c., to the basin in the interior of the works. By the side of this canal are to be found the pattern store, the delivery store, the general store, and the timber store. There is a yard for building iron river-boats, installed on the bank of the river; and there are also enormous depôts of timber of different sizes for the coal-pits, stores for the products of the rolling-mills and steel-works, &c.

The Castle of Seraing.—This comprises the residence of the Director-General, the Library, the Archives, the chamber reserved for the general meeting of shareholders (where in olden times the States-General of the Prince Bishop of Liége held their sittings), &c. A large building on the other side of the courtyard contains the office of the Secretary-General, the commercial and industrial offices, and that of the Chief Engineer, &c. Beyond this extend on one side the drawing offices, under the immediate direction of the latter, who has between forty-five and fifty engineers, draughtsmen, and tracers under him; on the other side are the Board and Committee-rooms of the Council of Administration and the office of the Director-General; then come the pattern shop and photographic studio.

Fitting Shops.—Workshop No. 1 was built in 1871. The roof on the "Raikem" or saw-tooth system has since been copied by the State and by the Northern Railway Company. It had not been used till then except for spinning mills. It presents the advantages of an equal distribution of light and air in every part, which is very advantageous for fitting work and for the health of the workmen.

The buildings forming the left wing enclose the Pattern shop, established in 1872, which is shop No. 2. Workshop No. 3 has been enlarged and rearranged successively in 1879 and 1881. Workshop No. 4, or the locomotive shop, was enlarged and modified in 1864. In Workshop No. 5 the large land and marine engines are erected. This building is lighted by night by the electric light, which is very favourable for erecting work. Workshop No. 6 is the bolt and nut making department.

The lifting cranes in the workshops are all worked by compressed air. A large 50-ton travelling crane is placed in the yard for handling and loading up heavy goods, such as locomotives.

Marie Pit.—This colliery, now in the middle of the works, was started in 1856, the pits being sunk by compressed air. Here was established in 1875, for the first time in Belgium, a system of central condensation of the steam from the various motors by means of a special condenser and air-pump. The plant comprises an air-compressing engine, first put down in 1871 to work the drills at the Caroline and Colard Pits. The centrifugal ventilator was erected in 1878, and is the first of the kind.

Forges.—This division contains a steam-hammer of 25 tons, erected in 1877, capable of forging cannon in steel of the largest calibre. There are also other hammers of less importance.

The small forges comprise hammers for the manufacture of wheels for locomotives and railway wagons, &c., and a lathe-shop for rough-turning these forgings. A large dining-room, with white marble tables, is placed between the hammer-shop and forges. Similar rooms exist in all departments for workmen who do not live in Seraing. They date from 1866, after the cholera epidemic.

Boiler Department.—All that remains of the old boiler-shop are the two large shops for the erection of boilers. The shop for plate-

flanging, and for the preparation of other parts of boilers, was erected in 1874. The large bridge-building shop and its annexes have been erected since 1880.

Blast-Furnaces.—Two of the three old furnaces make pig-iron from Luxembourg ore. The third makes hematite pig from Spanish and Algerian ores for the converters, as do also the four new furnaces at the Steel Works. They produce on an average about 50 tons of pig a day.

The large horizontal blowing engine, dating from 1860, was transformed into a compound engine in 1880; its power is from 270 to 300 HP.

These furnaces will probably be connected with the upper ore platform, similarly to those at the steel department; and the Luxembourg ore arriving by railway will be brought on to the platform in close proximity to the mouths of the furnaces.

The inclined planes used for elevating the slag and scoriæ from the iron mill were made in 1875.

Steel Works.—In 1866 these only comprised one 5-ton converter, and a rolling mill for rails and tyres; all the rest of this department has been constructed since 1866. The old foundry is transformed into a Siemens-Martin furnace shop. Of the four blast-furnaces alight, Nos. 1 and 2 were erected in 1871–72. They were rebuilt in 1881, and raised to the same height as Nos. 3 and 4 constructed in 1880–81. These four furnaces produce each 70 tons of pig for steel-making daily; and the metal can be run direct from them into the converter. The consumption of these furnaces in foreign ore is 180,000 to 200,000 tons, and the production of pig about 100,000 tons per annum.

The three large blowing-engines, which supply them with air, have a collective power of 600 HP. Two are sufficient for four furnaces, the third is held in reserve. They are of the type invented by the Society Cockerill, and used all over the world. Nearly 160 of these engines have come out of the Seraing workshops.

The Bessemer foundry contains four converters. The last pit is capable of producing by itself 300 tons of steel per diem. The Bessemer blowing engines are also on the Cockerill system. The

rail mills (roughing down and finishing) produced in 1878 as much as 2054 tons of rails in five days' work. The direct-acting reversing gear is the invention of the Society; its promptness of action is remarkable.

The tyre mill is able to roll tyres of nearly 2 metres diameter ($6\frac{1}{2}$ ft.), as well as ordinary sizes. It is by means of these powerful tools that the Society have been able to roll the large hoops required for guns, as furnished by the Society to the Italian, Dutch, and Belgian governments.

The steel works employ about 1540 workmen.

Foundries. — This department is composed of three large buildings, of which the two principal ones have been built since 1866, in strict accordance with all rules of health and convenience applicable to the moulders' industry: they are provided with ample means of transport and lifting, which allow of a considerable reduction in cost price. Since 1866 the Brass Foundry, Sand Store, Core-makers' shops, &c., have also been erected on the west side of this department.

Iron Works.—This division is perhaps the one that has undergone the least change since 1866. Nevertheless important improvements have also been made here. Dating from 1868, all the motors have been fitted with condensing apparatus; and boilers heated by coal have disappeared, steam being produced by the waste heat from the puddling and reheating furnaces. A train of rolls for large bars and rolled girders, with an engine of 280 HP., has been added; and the plate-mill, having become obsolete, has been altered and attached to a powerful reversing engine (the first on the Continent) of 550 HP., constructed in the works in 1868. A new plate-mill is in course of construction. The different buildings have also been renewed, and steam-hammers of the best system have replaced the old tools.

NOTES ON COLLIERIES VISITED AT LIÉGE.

The following notes on collieries visited in the course of the meeting at Liége were kindly prepared by Mr. Edgar P. Rathbone, of Westminster, F.G.S., Assoc. Inst. C.E.

COLLIERIES OF THE SOCIETY COCKERILL.

The collieries belonging to this company are situated on the works at Seraing, the finest of them being sunk on the ground immediately at the back of the blast furnaces.

There are three collieries in all, viz.: the "Marie," "Colard," and "Caroline." The last two are working at a depth of 525 yards from the surface.

The Colard Pit has been laid out in the most complete style, the plant being capable of raising 300 tons per day of ten hours from a depth of 750 yards.

The winding engine, which is of horizontal type and of American build, is fitted with the Society Cockerill's variable expansion gear, and has a spiral drum, the rope of which is made with a uniform decreasing section. The correct position of each spiral on this drum has been so carefully calculated that an almost perfect equilibrium has been obtained, and the drum works with scarcely any vibration or oscillation.

The iron head-gear is of simple and light construction, and is enclosed in a building, as is the custom on the Continent. The guide-rods are of wood, of a special design by M. Charles Lambert.

The shaft is 15 feet in diameter, and is divided into three compartments, of which two are for winding; the third, in the form of a half moon, being set apart for the pumps and ladders; and there is a small winding-shaft with a cage for the examination of the pumps, &c.

The pump is a rotary force-pump, double-acting, with condensers of the Rittinger type; it is worked expansively with a cut-off at

3-16ths of the stroke. It lifts 220,000 gallons per 10 hours. In the same house is a small capstan-engine for the service and pump repairs. The shaft is fitted with an iron lining in the upper part, in place of masonry.

The ventilation of the collieries is effected by six ventilators. At the Colard and Caroline pits they are of the old Fabry type. At the Caroline pit there is also a Guibal fan of the ordinary construction, and at the Marie pit a new form of turbine ventilator. This fan, designed by M. Kraft, is stated to be capable of exhausting 50,000 cubic feet of air per minute with 3-inch water-gauge. In this fan the air is conducted into a circular apparatus constructed much the same as a turbine-case, and certain fixed and curved vanes (*directrices*) guide the air into the blades of the revolving crown of the fan in such a manner that shocks and baffling of the air are greatly reduced, the air passing into the blades of the fan with very little friction. The blades of the fan likewise are so curved that the air is obliged to fill completely all the openings between them; this also has the effect of diminishing irregular movements in the fluid current. On leaving . the revolving crown the air still possesses a considerable velocity, the useful effect of which would be lost, if it were allowed to escape in this condition. In order to avoid this loss, the revolving crown is surrounded with another apparatus called the "diffusor," which presents a large area for the air to escape by, and thus diminishes the final velocity of the escaping current.

The whole fan is supported on a cast-iron column or pedestal 6 feet in diameter, which serves at the same time for conducting the air current into the fan from the drift leading from the shaft, and as a support for the small vertical engine which drives the fan. This engine consists of a small pair of vertical cylinders, bolted on to a bed-plate which is fixed directly to the side of the pedestal. The motion is transmitted to the fan by spur-gearing.

The manufacture of coke in Belgium has received much scientific attention, and many systems hardly known in England are in use there, such as the Appolt (well exemplified at the Society Cockerill's Works), and the Coppée, Smet, and Dulait.

The Appolt oven, although very costly in first construction, presents many advantages, especially great working capacity, economy in maintenance, &c. It is also considered most suitable for particular classes of Belgian coking coals.

Horloz Colliery.

The Horloz Colliery is typical of a colliery well laid out according to local conditions; it is economically managed, and has been a great financial success. There are some novel appliances at work: namely a Goffint ventilator, an air-compressor of the same type as that used so successfully in the works of the Arlberg tunnel, and a winding engine drawing from the ventilating shaft.

The Goffint fan has been described, and compared with other fans as to its efficiency, in a Report on Mechanical Ventilators prepared for the North of England Institute of Mining and Mechanical Engineers, vol. xxx., 1881, page 285.

Marihaye Collieries.

Vieille-Marihaye Colliery consists of three shafts, two for winding and pumping and one for ventilation only. The Pierre-Denis shaft is about 600 yards deep, with a diameter of 13 ft. The cages are fitted with Libotte's parachute, as a precaution against accidents from the rope breaking. The winding ropes are flat, and of aloe or Manilla fibre, as is usual at most collieries in Belgium. The average output is about 500 tons for a day of ten hours. The winding engine is of the vertical type, with 2 ft. 6 in. cylinders and 5 ft. 6 in. stroke. The ventilation is effected by means of four Fabry fans, 5 ft. radius and 10 ft. broad, exhausting 85,000 cubic feet of air per minute with 1½-inch water-gauge. They were made by the Ateliers de la Meuse Society.

There are two machines for supplying compressed air for the rock-drills in the mines, one of the Sommeiller type and the other of the Dubois and François. A large quantity of the coal raised has to be carefully screened and washed; and for this purpose there is a peculiar kind of vibrating screen which is said to do good work. The system of coal-washing is that of M. Bérard, which is well

exemplified at these collieries. There are over 100 coke ovens, all built on the Smet system. The system of endless-chain haulage is employed for transporting the coal from the shaft to the screens.

Nouvelle-Marihaye Colliery consists of two elliptical shafts, each divided into two separate compartments. The output here is over 300 tons per day of ten hours. The winding engine is vertical, with cylinders 2 ft. diameter and 5 ft. stroke.

Underground at these collieries a considerable amount of work has been done in driving stone-drifts with the Dubois and François rock-drill. In one stone-drift, the face of which had an area of 54 sq. ft., the drill advanced at the rate of nearly 6 feet per day of twenty-four hours, the rock being of a hard slaty character.

Hasard Collieries, near Micheroux.

This Company has a concession of over 4000 acres.

The discovery of this part of the Liége coalfield was due to a prospecting tunnel or level, known as the Laid Broly. This level, after being driven a distance of over 1800 yards, met, in January 1851, with an excellent seam of coal about three feet thick.

In 1857 the level known as Bay Bonnet was begun, but it took thirteen years to drive the whole distance of about 3500 yards. It has an average section of 10 ft. by 7 ft., and is used for bringing out the coal. The system of endless-chain haulage which is employed for this purpose appears to give every satisfaction. The power for the haulage is obtained from a horizontal engine of 100 HP., worked expansively, and with a condenser. At the same time that the level was being driven a shaft was sunk on it 130 yards deep, and from this shaft coal is also drawn. The Company has made rapid progress since the tunnel was completed, and at the present time may be counted as one of the largest and most influential enterprises in Belgium.

As the collieries are situated at some distance from any town or village, the Company have been obliged to build a small mining village for their workmen, which is of a model character. They have also built a large workmen's lodging-house, called the Hotel Louise, which cost, completely furnished, £7500, and will lodge 200

workmen, the cost of board and lodging per man being only 1*s.* 3*d.* per diem. Breakfasts and suppers are supplied at 2*d.* per meal, and dinners for 4½*d.* The Company became so well satisfied with the working of the Hotel Louise, that in 1874 they decided on building a second one large enough for 180 workmen.

These workmen's lodging-houses are well worthy of a visit, the arrangements for cooking and for washing the colliers' clothes being particularly well carried out.

Air-Compressors.—These are of the Sommeiller type, met with everywhere in Belgium.

Ventilation.—This is supplied by Guibal fans of the ordinary type and construction.

Mechanical Screening Arrangements. — The coal-screening arrangements at the Hasard Colliery are of the most interesting and instructive character; they are the invention of MM. d'Andrimont and Julian Léonard. The following is a brief description of their working. The coal, arriving in tubs or pit-wagons at the screening sheds, is tipped by automatic tiplers over two of M. Briart's screens with movable bars.* These screens separate the coal into two classes, ("Gaillettes" or large coal, and small coal), over and under 2½ in. diam. respectively. The smalls pass directly into hoppers, with sloping bottoms, so that the coal slides naturally into two bucket elevators, working at the lower end of the hoppers. These elevators deliver the coal into two cylindrical revolving screens, made with a double cylinder, one inside the other. The smalls are further separated by these revolving screens into three classes or sizes: namely, 2 in. diam. or "Gailletins," 1 in. or "Petits Gailletins," and under 1 in. or "Menu," the smallest size, used for making patent fuel. This small coal is first washed in a machine invented by M. Bérard, and then passes into a large hopper capable of holding 15 tons, from which it is run out into wagons and taken to the briquette or patent-fuel works.

The largest size of the small coal, or "Gailletins," passes out of the end of the inside frame of the screen on to an endless travelling

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* See description of Mariemont Collieries, *infra*, p. 571.

band, at the side of which women or boys stand and pick off the dirt. These bands, which run on iron rollers, are made of strands of aloe-fibre, and are provided with a tightening apparatus.

The bands deliver the coal on to two platforms, the floors of which are also fitted with a screen of fine mesh, so as finally to separate any small coal. The platforms also are so arranged that the coal upon them may be lowered into the trucks below, without being subjected to any further rough handling.

The "Petits Gailletins," or medium-size small-coal, passing out of the end of the outside frame of the revolving screen, is delivered similarly on to endless travelling bands, where it is cleaned. If the consumer desires it, he can have these coals washed, in which case they are conducted by another endless band, first into a small screen with fine mesh and percussive motion so as to separate the dust, and then into a coal-washer of the Bérard type.

The large coal, or "Gaillettes," passing over the Briart screens, falls on to percussion frames, by which means it is jogged forward, without much shock, on to endless bands, where the dirt is picked out, the coal being separated also by hand into different sizes. The bands deliver the coal into iron shoots fitted with movable spouts, so that the coal can be charged into any part of the railway truck, with the least possible amount of breakage. The very large lumps or best coals are separated out by hand from the "Gaillettes," and placed upon another endless band, which transports them into shoots similar to those just described.

It is estimated that the two revolving screens together screen 400 tons of coal per day of ten hours, and produce 40 to 50 tons of "Gailletins" and 60 to 70 tons of "Gaillettes" or large coal. The motive power for all these screening arrangements is derived from a pair of small horizontal engines of 30 HP.

WORKS OF THE ATELIERS DE LA MEUSE.

(NOTE SUPPLIED BY THE MANAGING DIRECTOR, M. A. STÉVART.)

This Company (La Société des Ateliers de Construction de la Meuse) was founded on January 1st, 1873, succeeding to the firm of Charles Marcellis, whose works were at Boverie-lez-Liége. On 1st November in the same year the works were transferred to Val-Benoît, where they occupy altogether a space of 50,000 square metres (12 acres). The workshops, properly so called, cover 12,500 square metres (3 acres) and form a single block in one continuous length of 245 metres (270 yards).

The firm of Charles Marcellis was founded in 1835. Amongst the most important productions of the first year after its establishment may be mentioned numerous roofs and bridges in iron; and later, steam engines and mechanical appliances of all kinds, as well as railway plant. At present the winding engines, pumping engines, and ventilating engines of the firm are to be seen in almost all the important collieries of the Liége district, and in other coalfields both in Belgium and abroad. They are also to be found in metalliferous mines of the highest importance, such as those of Bleyberg, those of the Vieille Montagne Company, both in Belgium and abroad, those of Le Rocheux, of Velaine, of Lintorf in Prussia, of Monteponi in Sardinia, and of Linares in Spain.

The Company also constructs engines and appliances for metallurgical works, for blast-furnaces, iron and steel works, &c.; marine engines and hulls of boats (for which there is a special shop), steam dredges and marine boilers; hydraulic plant, including motor engines, accumulators, and cranes; sugar mills; and lastly all kinds of articles relating to mechanical construction, carpentry, boiler making, and iron founding.

DESCRIPTION OF THE SCLESSIN WORKS.

[Abstracted from a pamphlet by M. Jules Dallemagne, Managing Director.]

The Society was started in 1828, simply to work the colliery of Bois d'Avroy. They gradually acquired other collieries and iron mines, and became successively makers of pig iron and of wrought iron, especially rails and girders. The latter trade gradually became the principal one; workshops were built, and the collieries were some of them formed into distinct companies. Their present undertakings may be described as follows:—

1. Iron mines near Athus in Luxembourg supplying about 300 tons of ore per day, and a mine at Couthuin supplying about the same quantity. The latter is connected with the Meuse by an adit, through which the ore is brought out and loaded direct on to barges, or on to the trucks of the Northern railway.

2. The colliery of Bois d'Avroy, having two pits, and yielding about 300 tons per day from each.

3. Two blast-furnaces, utilising the whole of the ore supplied from the mines. They are built on pillars, according to the most recent system, with open hearth; their height is 20 metres (66 ft). The gas is taken off by a single opening in the side of the furnace. The blast has a temperature of 650° to 700° C. (1200° to 1300° F.), and is supplied by four Whitwell stoves to each furnace. There are three blowing engines of the Woolf compound system, and with condensers, each having a power of 100 HP. Each furnace produces per 24 hours 100 tons of white finery iron, consuming 98 to 100 tons of coke and 300 tons of ore. The ore used comes from the Jurassic beds of Luxembourg, and from calcareous specular beds at Java near Huy, in the carboniferous series. The ore is brought by railway direct to the mixing sheds, where it is discharged, broken up, and loaded into tipping wagons to be conveyed to the lift. Part

of the furnace gases are used to heat ten horizontal boilers, which supply steam to the works.

4. Coke ovens, 108 in number, of a horizontal kind peculiar to these works. The coal used comes partly from the Society's colliery and partly from elsewhere.

5. A foundry, with two cupolas and a steam lift. It is chiefly used for the articles required in the machine shops and rolling mills of the works.

6. Gas works, in three groups, each containing seven fire-clay retorts, and each distilling 45 kilos (100 lbs.) of coal per hour.

7. Rolling mills, comprising thirty puddling furnaces, and thirteen heating furnaces; also thirty-five boilers, heated by the waste heat, and supplying steam to fifty-two steam engines of 1500 HP. total. There are ten trains of rolls, two being for roughing down, one for scrap, one for plates, three for merchant iron, and three for girders, &c. The total production is 30,000 tons per annum in girders, angles, tees, and other special sections, as well as merchant iron and plates. The finished iron is loaded on wagons running upon a sunken railway, so as to give no trouble in lifting.

8. Machine shops. These commenced work about 1860, chiefly in making girders and bridges. In 1874 the ironwork for the Syzrane bridge over the Volga (the longest in Europe, being 4730 ft. long, and weighing 7500 tons) was constructed here. The shops comprise forge, boiler shop, erecting shop, and open yard for large bridges. In addition to girder work they supply railway plant, such as traversers, two of which, for locomotives and worked by steam, were in hand at the time of the visit. The total production is from 6000 to 8000 tons per annum.

The Society possesses several institutions for the benefit of the workmen, such as schools, containing more than 800 pupils, a sick club, pension club, musical club, &c.

DESCRIPTION OF THE ANGLEUR STEEL WORKS.

By M. ROSSIUS, Managing Director.

The Society manufacture steel by the Bessemer process, in all qualities from the softest to the hardest. The metal is not run direct from the blast-furnace, but is remelted. There are six converters, of which four of 6 tons each are employed on the Thomas-Gilchrist process, and two of 7 tons each on the ordinary Bessemer process. There are two blowing engines with separate condensers, two hydraulic accumulators, nine hydraulic cranes &c. There are seven steam hammers, the heaviest being of 15 tons. The rolling mill comprises:—(1) A three-high train of rolls 0·65 m. diam. (26 in.), driven by a vertical condensing engine, cylinder diameter 1·15 metre (46 in.), stroke 1·4 metre (56 in.); (2) A three-high train for billets and rails, driven by a vertical engine, cylinder diameter 1·00 metre (39 in.), stroke 0·80 metre (33 in.); (3) A train for spring steel &c., driven by a vertical engine, cylinder diameter 0·65 m. (26 in.), stroke 0·90 m. (36 in.); (4) A horizontal tyre-mill. There are the ordinary appliances, such as saws, straightening and bending presses, drills, &c. At Renory the Society possesses also a wire mill with a roughing train, finishing train, &c. They also own coke-ovens at Tilleur near Liége, and two blast-furnaces at Audun-le-Tiche in Lorraine. These furnaces supply a part of the pig iron for the basic process. The ore is derived from mines owned by the company. The production of the company consists chiefly of rails, tyres, both for locomotives and wagons, railway springs, steel castings, and steel forgings.

DESCRIPTION OF THE BLAST-FURNACES AND COLLIERIES AT OUGRÉE.

SUPPLIED BY THE KINDNESS OF THE MANAGING DIRECTOR, M. L. CHENEUX.

Blast Furnaces.—These are four in number, of which three have been rebuilt one after another since 1878. They are 17 metres high (55·8 ft.), and 5·25 metres (17·2 ft.) in diameter at the boshes. Their interior capacity is 246 cubic metres (8700 c. ft.). The daily make of each furnace is, in round numbers, 60 tons. The make from two furnaces, during the business year 1881–1882, was 41,000 tons. The qualities are the following:—

(1) Strong white pig.
(2) Spiegel pig for fine-grained or Best-Best iron.
(3) Bessemer pig.
(4) Pig for the Basic process.

The ores used for ordinary puddling pig come from the province of Namur and from Luxemburg; those for steel pig are imported from Germany, Spain, and Greece. The coke is produced in the Society's own ovens: the flux comes from Chokier, in the province of Liége. The throat of the furnace is open, and the gases are taken off by a central flue, having in two of the furnaces a diameter of 1·80 metres (5·9 ft.), and in the other two of 2·50 metres (8·2 ft.). In the third furnace the gas is deprived of its dust by circular "washers" placed round the furnace. This gas suffices for heating the air, and for producing the steam required to work the lifts, the blowing engine, and the accessory engines.

The blast is heated by fire-brick stoves on the Whitwell system, four to each furnace. Their height is 13·2 metres (43·3 ft.); diameter 5·5 metres (18 ft.); and the temperature of the air 550° C. or 1000° F. The blowing engines are three in number: two of them are beam engines on the Evans system, with a blowing cylinder 1·80 m. in

diameter (5·9 ft.), and 2·4 metres stroke (7·7 ft.). The third engine is of the Seraing type, with a blowing cylinder 2·65 m. in diameter (8·7 ft.) and 2·4 m. stroke (7·7 ft.). Steam is generated by seven boilers on the Jumeli system, tested to 5 atmospheres (75 lbs. per sq. in.). Each boiler is composed of two shells 0·9 m. in diameter (2·95 ft.), and 12 m. long (39·37 ft.). Each of these has below it a heating tube 0·70 m. in diameter (2·3 ft.), and 10·50 m. long (34·4 ft.). The two shells are independent of each other, and merely have the fire in common.

Coke Ovens.—Since 1871 the Society has by degrees replaced all its horizontal ovens by ovens on the Appolt system. It now possesses ten sets of these ovens, each having eighteen compartments, and each producing 16½ tons of coke in the 24 hours. The total production for the commercial year 1881–82 was 55,000 tons. The proportion of coke yielded was 80 per cent. of the original coal, which contains 17·5 per cent. of gas, and which if burned in the raw state gives 18 per cent. of ash. The preparation of the coal consists in screening it to three different sizes, with the following results:—

(*a*) 41 per cent. of small coal, less than 6 millimetres (¼ inch) in diameter, and giving 7·8 per cent. of ash.

(*b*) 22 per cent. of large coal, above 35 millimetres in diameter (1·4 in.), and giving 13·1 per cent. of ash. After hand picking, to get rid of the stone, the proportion of ash falls to 4·8 per cent.

(*c*) 37 per cent. of rough slack between 6 and 35 millimetres in diameter, and containing the greater part of the stone. This coal contains 20·4 per cent. of ash, but after washing this is reduced to 5·2 per cent.

The three sizes are subsequently brought together, crushed, and mixed: the mixture contains 7·5 per cent. of ash, and the coke contains 9·5 per cent. This preparation has amongst other results the effect of reducing by 35 per cent. the proportion of phosphorus existing in the coal, and by 50 per cent. the proportion of sulphur. The coke contains 0·033 per cent. of phosphorus, and 0·2 per cent. of sulphur.

Collieries.—The collieries at Ougrée have an extent of 378 hectares (934 acres), and contain six seams varying in thickness from

0·55 m. to 1·1 m. (1·8 ft. to 3·6 ft.). The quantity raised during the commercial year 1881–82 was 86,000 tons. The coal is moderately bituminous. The depth of the workings is 300 m. (984 ft.). The winding engine, erected in 1873, has two vertical cylinders 0·60 m. in diameter (23·6 in.), and has valves moved by cams. The pumping engine is direct-acting and condensing, without expansion. The diameter of the steam piston is 1·50 m. (59·1 in.); and that of the pumps is 0·40 m. (15·75 in.). The stroke is 2·17 m. (85·4 in.). There is a dam which keeps back the water at a level of 108 m. below the surface (354 ft.).

Workmen's Town.—At Renory, on the borders of the district of Ougrée, the Society possesses a "workmen's town" commenced in 1873. The houses are placed to face E.S.E., which is the most favourable aspect under the prevailing winds, and gives sufficient sunshine. They are grouped two, three, and four together, and arranged to have plenty of light and air. There is as much variety as possible in their appearance. Each is surrounded by a garden, which, on an average, contains 300 sq. metres (3230 sq. ft.). They all have cellars, and are of two types—one of them having two rooms to each floor, and the other only one. One-third of the houses are allowed to take lodgers, and have a special room for the purpose, divided into three compartments by partitions at the height of a man. There is a well for every eight houses, giving an ample water supply. The gardens are divided by fences partly of stone, partly of cast iron, and partly of wood. The rent is 15 francs per month for the larger houses, or 20 francs if there is a lodger's room; and 12 francs for the smaller houses. The taking, giving up, and maintenance of the houses, are under strict rules, a copy of which is fixed in each house.

DESCRIPTION OF THE OUGRÉE IRON AND STEEL WORKS.

SUPPLIED BY THE KINDNESS OF THE MANAGING DIRECTOR, M. A. RAZE.

The manufactures at these works are merchant iron, puddled steel, and fine-grained or Best-Best iron; also girder and boiler plates, axles and tyres for carriages and engines (both in steel, fine-grained iron and puddled steel), steel rails, and every kind of rolled steel, such as bars for railway springs, mining drills, &c.

The works comprise:—

(1) A puddler's shop having fifteen double furnaces, two roughing trains, and three shingling hammers. The production in puddle bar is 75 tons per 24 hours: the pig being the white pig of the Ougrée furnaces.

(2) A Bessemer shop with two 7-ton converters.

(3) A plate-rolling mill with a 5-ton hammer and three heating furnaces.

(4) A merchant mill with three heating furnaces, and a mill for small bars with one furnace.

(5) A tyre mill, with three hammers of 7 tons and one of 15 tons, and with five heating furnaces.

(6) An erecting-shop, a forge for axles, a boiler-shop, and a foundry.

A new rail-mill with three-high rolls is in course of construction.

The Society own five-eighths of the colliery of Six-Bonniers, and take the whole of the output belonging to them for their own consumption.

In 1872 the Society applied the Bicheroux system to its heating furnaces, and in 1876 to its puddling furnaces. For the last two years every furnace in the works has been upon this system. With regard to re-heating, exact figures are impossible, but the advantages

are equal to those in puddling; and the saving is not less than 25 per cent.

The Bicheroux puddling furnace consists of—

(1) A gas generator, receiving only a small quantity of air, so as to produce carbonic oxide.

(2) A mixing chamber, into which this gas is drawn, together with external air, and where its combustion commences.

(3) A furnace where the combustion is completed, and where the puddling goes on.

The dimensions given to these three chambers vary greatly with the composition of the coal, &c., as does also the size of the flues. The air which enters the mixing chamber passes first under the bottom of the furnace and along its walls; this giving the double advantage that these parts are kept cool whilst the air is heated. The gas which escapes from the furnace incompletely burned is used for heating boilers, as in ordinary puddling furnaces. The working is very easy, so that the dimensions of the puddling furnace can be increased, and two working doors are given to each furnace on opposite sides.

The advantages of the system are as follows:—

(1) *Saving of fuel.*—The puddling of ordinary white pig from Ougrée required with the old furnaces 900 to 1000 kgs. of coal per 1000 kgs. of puddled bar; with the new furnace it requires only 600 kgs. Fine-grained iron, which used to require 1300 to 1500 kgs., now requires only 800 kgs. There is the further advantage that large coal is not required; slack screened to ¾ in. diameter acts perfectly well. The coal used contains only 18 to 20 per cent. of gas, and other coals from the same basin have been employed with equal success.

(2) *Saving in yield and improvement in quality.*—The saving in yield is from 3 to 4 per cent.; the loss in puddle bar being only 9 to 10 per cent. on the pig, instead of 13 to 15 per cent. as formerly. At the same time the quality is improved, from the complete exclusion of cold air, which cannot come either through the fire-holes or through the grate, the latter being always covered with a thick layer of coal.

(3) *Saving in repairs.*—The two doors allow easy access to all parts of the floor, which can thus be kept in perfect repair; and as the coal is never in contact with the bridge, the latter lasts much longer, often for several weeks.

(4) *Durability of the fire-bars.*—This is due to the low temperature of the hearth and the quantity of clinkers which can be left upon the grate. Fire-bars about 1¼ in. square are found to have their edges sharp after five months' working.

(5) *Improvement in the condition of the workmen.*—With the same rate per ton, a puddler working at this furnace can earn 25 to 30 per cent. more than at an ordinary furnace.

The first cost is less than that of two ordinary furnaces, the production of which is together scarcely greater than that of one gas furnace. Many parts belonging to the old furnace can be used for the new. The workmen soon become accustomed to the work, and it is never necessary to send special workmen to an establishment on its first adopting the system. The number of master puddlers in the works may be diminished by about one-half, and the number of tools to be kept in order in the same proportion. The first cost is not above 2000 francs per furnace (£80). The steam produced is the same as from two ordinary furnaces, and the gases are completely burned by the time they arrive at the chimney. The bottom of the furnace, the means of cooling the bridges, &c., &c., can be arranged exactly as usual. Finally, the cleaning of the grates is less troublesome than with ordinary furnaces.

NOTE ON THE VAL ST. LAMBERT GLASS WORKS.

(PREPARED UNDER THE SUPERINTENDENCE OF M. JULES DEPREZ, MANAGING DIRECTOR.)

This Society has existed since 1825, its works partly occupying an ancient convent of the same name. It has increased rapidly since 1850, and now has eight shops, with twenty furnaces, and occupying an area of more than 6000 square metres (1½ acre). The raw materials are prepared in special rooms at the works. The sand is washed, the potash and saltpetre refined, and the red lead is manufactured. The pots or crucibles required are also made on the spot with the greatest care. The furnaces are rectangular, oval, or circular, and some of them are worked by gas on the Siemens system. Each contains twelve to fourteen crucibles. The waste heat is employed for generating steam in Belleville boilers: the steam being used for working the machines which cut the glass. Formerly the cutters were worked with foot-lathes, with which light work was alone possible. Afterwards a water-wheel was employed, but in 1846 the first steam engine was erected, and within a year the whole of the cutters were supplied with steam power. There are four of these cutting shops, and the total number of lathes is 800.

The engraving on glass still continues to a great extent in its original form, that is to say, by a small wheel worked with the foot. Three systems have been introduced in succession as substitutes. The first works by means of fluoric acid, the pattern being traced in a special ink. In the second system the same acid is employed, but the pattern is cut by the point of a chasing machine in a coating spread over the glass. The third method is the sand blast of Tilghman.

The whole works are lighted by their own gas, and are connected by branch railways with the line from Liége to Namur and with the Meuse. In addition to the glass works proper there are fitting shops, chiefly used for constructing the moulds; also forges, shops

for making packing cases, stores, packing rooms, &c. The total make is about 120,000 articles per day. To pack this quantity there are used each month 50 tons of hay, 55 tons of straw, and 250,000 feet run of boards. The works consume each year 7,000 tons of sand, and 1,500 tons of fire-clay. The total weight delivered from the works is 9,000 tons per annum.

The works possess schools for the children of the workmen, especially a School of Design and a School of Music. They have also 186 workmen's houses, each with a garden, as well as sixteen model dwellings at Ivoz. There is a Savings Bank and Investment Society for the workmen, and also a Sick Fund. The Society has also founded a co-operative store for the workmen, and societies for music, choral singing, gymnastics, &c.

NOTES ON THE MANUFACTURES OF VERVIERS.

BY M. ÉDOUARD PELTZER, JUN., OF VERVIERS.

The industrial district of Verviers, one of the most important in Belgium, having a population of 75,000, comprises several communes, of which the chief are Verviers, Dison, Hodimont, Dolhain, Ensival, and Pepinster. The principal industry is the making of woollen yarns and woollen cloth. Other trades which are dependent on this, such as the construction of steam engines and of machinery peculiar to the woollen trade, carding, tanning, &c., complete the facilities offered by the district of Verviers for the working of wool.

The proximity of the coalfields of Liége and Herve ensures a supply of the necessary fuel under favourable conditions. The great reservoir of La Gileppe, formed by the largest dam in the world, furnishes the works with water of perfect purity. The content of this reservoir is 13,000,000 cubic metres. Assuming that it is filled twice in the year, it appears that more than 25,000,000 cubic metres of water are placed annually at the disposal of the trade. Water is supplied to large users at 1½ centimes per cubic metre, and to others at 5 centimes. In 1882 the town sold 14,000,000 cubic metres of water for trade purposes, and 350,000 cubic metres for domestic purposes.

Its central position, numerous lines of railways, and proximity to the port of Antwerp, place the district in communication with every part of the globe, both as regards the supply of raw material and the delivery of manufactured products. The following figures will give an idea of the commercial movement in the district.

The importation of raw wool is on an average 150,000 bales per annum, weighing about 48,000,000 kilogrammes. They come from Buenos Ayres, Monte Video, Sydney, Melbourne, the Cape, &c.

The exportation is about 9000 bales per annum, weighing about 2,000,000 kilogrammes. Hence there remain about 46,000,000 kilog. which are worked up in the district, and which represent about 16,000,000 kilog. of washed wool. To these have to be added the washed wool imported (skin wool from the south of France, &c.), which is about 2,000,000 kilog. There is thus a total of 18,000,000 kilog. of washed wool to account for. Of this, 11,000,000 are exported to Germany, Russia, Holland, Austria, &c.; and 7,000,000, together with 3,000,000 to 4,000,000 kilog. of secondary products, such as noils, waste, &c., are used up in the spinning mills. The woollen yarn exported is to the amount of 8,000,000 kilog., and the cloth 2,500,000 kilog. The markets for yarns do not extend beyond Europe, and are chiefly in England, Scotland, and Germany; but the cloth is sent throughout the world, and includes every quality from the finest to the most common.

WOOL-WASHING WORKS OF M. EUGÈNE MÉLEN.

A. *Washing.*—The processes here are as follows:—

(1) Sorting (*Triage*), or separation of the fleece into different divisions according to the quality of the wool as to fineness, length, &c.

(2) Washing (*Lavage*), which takes place in hot baths, made alkaline by soda, and is done by the washing machine called the "Leviathan." The wool is passed through these baths successively by self-acting machinery.

(3) Drying (*Essorage*) by the hydro-extractor.

(4) Final drying by hot air (*Séchage*), the wool being stationary or having merely a motion of translation. The drying in the latter case is of a more regular character.

(5) Mechanical cleaning (*Échardonnage*) by a cleaning machine. It is this process that has brought the Buenos Ayres wool into such extensive use.

B. *Chemical Cleaning.*—Generally applied to the waste products of the wool, and sometimes to the wool itself. The object here is to separate from the woollen fibre all the vegetable substances, such as

seeds, thistles, &c., which cannot be separated by mechanical means. The operations are:—

(1) Dipping in acid baths (*Trempage*) with subsequent drying.

(2) Charring (*Carbonisage*), the wool being exposed to a strong heat in a furnace, whereby the thistles, &c., become black and friable.

(3) Beating (*Battage*), to knock out the impurities, and leave a material ready for spinning, which, if not equal to the wool itself, is still an excellent raw material, formerly lost. The machine here used is an invention of the late M. Mélon.

(4) Placing in alkaline baths (*Désacidage*), to remove the last traces of acid; and drying by hot air.

The motive power used in the works consists of a multi-tubular boiler on the Pétry-Chaudoir system, and a twin steam-engine on the Gorissen system.

LA VESDRE WOOL-COMBING AND SPINNING WORKS.

(Managing Director: M. Math. Drèze-Rick.)

A. *Combing.*—The operations here are as follows:—

(1) Sorting; washing by soap in a washing machine constructed by the Société de Constructions Mécaniques of Verviers; partial drying on the Méhl drum, and automatic oiling (*Ensimage*).

(2) Carding (*Cardage*). The object here is simply to lay the fibres roughly parallel to each other. The wool when carded is brought into slivers by passing it through a funnel.

(3) Drawing before combing (*Étirage avant Peignage*). The machines for this purpose unite several of the slivers into a single sliver of the same diameter, by forcing them between the teeth of a cylinder furnished with combs, called "hérissons" (porcupines). The fibres are thus drawn out and laid sufficiently parallel for combing.

(4) Combing (*Peignage*). This is the most important process. The combing machines separate the long from the short fibres, and also comb out all the impurities, such as buttons, burrs, &c. The long fibres form the top, the short fibres the noils. Heilmann was

the inventor of the ingenious mechanism which forms the basis of the combing machines of Schlumberger, Meunier, Barbier, &c., which are chiefly employed at Verviers.

(5) The slivers which leave the combing machine have very little strength. The doubling machine (*Vide-pots*) doubles these on each other, and gives them greater solidity by means of friction and drawing.

(6) The drawing before backwashing (*Étirage avant Lissage*) completes the work of the doubling machine.

(7) Backwashing (*Lissage*) cleans the wool of grease, &c., and smoothes the slivers, laying every fibre flat so as to give a more brilliant appearance to the wool, which is now ready for spinning. The process consists in passing the slivers first through baths of soap and water and then over cylinders heated by steam, and made by Skene and Devallée, of Roubaix.

B. *Spinning.*—The processes are the following:—

(1) Preparation. The combed sliver is equalised and thinned down by passing it successively through roving frames analogous to those employed in combing.

(2) Spinning (*Filature*). Here self-acting mules are alone employed. They draw out the sliver to any required thickness, giving it at the same time the twist which is necessary for its strength.

(3) Folding (*Retordage*), or joining two or more threads into a single one, in order to obtain a yarn of greater strength. Colouring effects are often produced by folding threads of different shades.

Dyeing may be carried out on the sliver or on the yarn. Generally the former method is employed. The combed sliver after smoothing is divided into skeins, which are hung upon bars above the dyeing vats.

The motive power is given by means of boilers having 280 square metres of heating surface, and built by Mathot and Bailly, of Chênée. There is a condensing steam engine of 250 HP., built by the Société de Constructions Mécaniques on the Bède and Farcot system, and having variable expansion worked by the governor.

SPINNING WORKS FOR CARDED WOOL, OF M. HAUZEUR-GÉRARD FILS.

The processes here are as follows:—

(1) Greasing or oiling (*Ensimage*), generally by oleine.

(2) Carding (*Cardage*). Here there are three machines: the Breaker or Scribbler (*Ploqueteuse*), the Clearer (*Repasseuse*), and the Condenser (*Continue*). The two first open the fibres of the wool, forming it into a film, called first or second "mapping;" whilst the third divides this film and transforms it by rubbing into rovings.

(3) Spinning. This is done by self-acting mules, generally of English make, either by Messrs. Platt Brothers or Messrs. Parr Curtis and Co.; or else by the frame spinning machines of Célestin Martin of Verviers. In the first system the drawing and twisting of the yarn are produced by the advance of the carriage and the rotary motion of the spindles. In the second the two operations are done separately, but one immediately after the other.

(4) Folding, as above described. This is done by special machines, built by Sykes, Hetherington, &c.

(5) The yarn must be reeled. The machines for this purpose (*Dévidage*) are provided with an arrangement which stops the whole machine if a single thread breaks (Snoeck's system).

The motive power is given by tubular boilers with two heating-tubes, and by a steam engine built by Nollet, of Ghent.

MANUFACTURE OF CLOTH, SATIN, WORSTED, AND WOOLLEN GOODS, BY MESSRS. PELTZER ET FILS.

In these works, which employ 1700 workmen, the whole of the operations above described are in use, the wool coming into them in the fleece, and going out as cloth, &c. But only the processes for "Weaving and Finishing" are here dealt with. These processes are as follows:—

(1) Warping (*Ourdissage*), the object of which is to lay the threads in the proper order.

(2) Dressing or Sizing (*Encollage*): passing the threads through

a bath of size, to give them more strength when undergoing the severe treatment of the loom.

(3) Weaving (*Tissage*). The tissue is formed by the crossing of two series of threads lying at right angles to each other. That which is lengthwise to the piece is the warp, the other is the weft. The loom locks these two together at each "shoot of the weft;" the warp is separated into two portions, one half moving upwards and the other downwards, and these hold the weft between them. The looms are made in England, Germany, or Belgium.

(4) Milling and washing (*Foulage et Lavage*). These operations are with the object of tightening the tissue, so as to give it more strength, whilst at the same time preserving its suppleness and elasticity.* They also serve to clean the piece from the oil which is still contained in it, and which has been imparted to the wool before spinning.

(5) Teasing (*Garnissage* or *Lainage*). Milling forms upon the piece a sort of down, consisting of filaments standing up irregularly from the surface. These must be drawn up and ranged parallel to each other. This is accomplished by a machine carrying frames which are set with teasles.

(6) Tentering (*Ramage*), which is done either on tenter frames or in special machines.

(7) Shearing (*Tondage*), which gives a uniform length and appearance to the filaments.

(8) Pressing (*Pressage*), which consists in exposing the cloth to the simultaneous action of a high temperature and a considerable pressure, under hydraulic presses or rolls. It is this operation which gives the brilliance to the cloth.

(9) Steaming (*Décatissage*), which is simply to fix the lustre by means of steam at low pressure passing over the pieces of cloth, which are rolled on perforated copper cylinders.

The motive power is given by tubular boilers on the Fairbairn system, and by two vertical engines, one high-pressure, and the other low-pressure receiving the exhaust steam of the first.

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* They are carried on in a separate establishment at Renoupré, to the east of the town.

WOOL-CARD MANUFACTORY OF M. DUESBERG-DELREZ.

The processes here are:—

(1) Cutting and preparation of the leather.

(2) Setting of the points of the cards upon ribbons or strips of leather; or in other cases of leather and felt, of cloth and felt, or of cloth only. This is done by very ingenious machinery.

(3) Sharpening and finishing the points of the cards with emery polishers.

The motive power is given by a boiler with two heating-tubes, and by an engine with variable expansion worked from the governor, and built by the Société de Constructions Mécaniques of Verviers.

LA GILEPPE RESERVOIR DAM.

[The following notice is abstracted from a paper by MM. M. Bodson, E. Detienne, and F. Leclercq, prepared for the Association of Engineers from the University of Liége.]

The construction of the reservoir at La Gileppe, which is closed by the largest masonry dam in the world, was rendered necessary by the large demand for water in the town of Verviers, not only for drinking purposes but for the washing of wool &c. in the large cloth manufactories of the town. In 1857 the question of waterworks for Verviers was put into the hands of M. Bidaut. It was decided that the requirements should be placed at 40,000 cubic metres per day (8,800,000 gallons), and that the water must be very pure, specially as regards lime. The Gileppe river entering the Vesdre a few miles above Verviers (see district map, Plate 29), satisfied all the conditions and was chosen accordingly. After a careful examination a finished design was presented in 1868. In April 1869 the works of the dam were commenced, and they were completed on the 1st November 1875. In order to give sufficient storage capacity it was necessary to have a dam with a height of no less than 45 metres (148 ft.); which was not however without precedent, as the dam at Furens, then under construction, has a height of 51 metres (167 ft.). The actual height of the parapet at La Gileppe is 2 metres more, or 47 metres (154 ft.); but the by-wash at each side keeps the reservoir at the normal level of 45 metres above the base. The water is taken from the reservoir by two subterranean galleries C C, Fig. 1, Plate 53, each in connection with a shaft D, through which the valves are manipulated. During the construction these galleries were utilised for carrying off the water of the river. They are lined throughout their length, the sides being in masonry and the arch in brickwork. Their construction was the first work undertaken, and was completed in May, 1869. They gave valuable

information as to the nature of the rock, which was found to lie regularly in almost vertical beds, and to yield very little water.

In the construction of the dam itself it was specially necessary that it should be solidly united with the rock at each end, and also that there should be the closest possible junction between the base of the masonry and the ground beneath it, to prevent all chance of leakage. The first thing was to settle the ground plan and section of the dam. The former was made in the shape of a curve, concave to the reservoir, probably with the view that something of the advantage of an arch would thereby be obtained. The radius of the curve was 500 metres (550 yards). With regard to the section, the engineer was chiefly guided by the two great dams of Alicante and Furens (Saint-Étienne), shown in Figs. 3 and 4, Plate 53; but it is made wider than either of these both at top and at bottom. The actual section is shown in Fig. 2. His reason for these ample dimensions was probably that the quantity of water in the reservoir was much larger than in the other cases, and also that the dam itself was much longer. The form of the slope in the rear was so arranged as to give the utmost strength both against the overturning of the dam and against sliding at the base. The latter was also prevented by the stepping of the masonry into the rock, Fig. 2, which offered every guarantee against leakage. The masonry was entirely of limestone, chiefly brought from Béthane on the right bank of the Vesdre, opposite to the Gileppe valley. Part of the masonry on the inside was of stone obtained on the spot. It was not laid in regular courses, but with a very large number of headers amongst the stretchers, so as to unite the whole mass firmly together. The dressed stones for the faces were laid exactly tangential to the curve; behind these were placed rough hewn stones laid at right angles to the curve, and the interior was then filled in with rubble. Before laying a fresh course the upper surface was carefully cleaned, and covered with a layer of mortar sufficiently liquid to run into the holes, &c. This mortar was composed of five parts of lime, four parts of sand, and one of trass. The by-washes B B, Fig. 1, are in the form of steep channels cut in the solid rock. At the upper end the width is 25 metres (82 ft.), which is amply sufficient for the

discharge of the water, even in the highest floods. The slope from thence downwards varies from 1 in 10 to 1 in 2½. Above them the earth is dressed back to a slope of 1 in 4.

The water is taken off from the reservoir through the two galleries already described, which lie in the shape of a horse-shoe round the dam, as seen in Fig. 1. At the entrance end of each is a grating A for the purpose of filtration. Passing through this the water flows through the gallery till it reaches the sluices O. Here the gallery is closed by a mass of masonry, through which are laid two cast-iron pipes of 0·85 metre diameter (34 in.). Through these the water passes into the working chamber. Each pipe is closed at the lower end by a self-acting valve, beyond which is another pipe of the same diameter leading to a double-beat valve placed in the shaft D, and worked by gearing from this shaft. After passing this chamber the water arrives at another dam of masonry P, also provided with double-beat valves. Immediately below this is the safety-sluice V. From this point the two pipes continue of the same diameter as before to the outer end of the gallery. Gradually turning towards each other, the two galleries are united at F, where there is a junction valve. A little on one side of this valve two pipes K lead off from the pipes coming from the left bank, and conduct the water to a well I, from whence starts the aqueduct leading to Verviers. Before entering the aqueduct the water passes through a measuring apparatus. A set of sluices at F enable water to be discharged from the reservoir into the old bed of the river, so as to maintain a better level in the Vesdre in time of drought.

The dimensions &c. of the dam are given below.

Total height	47 metres.	154 feet.
Height to level of water .	45 „	148 „
Length at base	82 „	269 „
Length at coping . . .	235 „	771 „
Thickness at bottom . .	65·82 „	216 „
Thickness at coping . .	15 „	49 „
Total content of masonry .	248,470 m. cb.	8,774,870 cb. ft.
Weight	574,481,000 kg. .	571,481 tons.
Section at greatest height	1720 sq. m.	18,510 sq. ft.
Area of reservoir . . .	80·05 hectares.	197·8 acres.
Content of reservoir . .	12,238,916 m. cb.	432,224,663 cb. ft.

The centre of the coping is occupied by a lion in sandstone, resting on a granite base, 8 metres high ($26\frac{1}{4}$ ft.). It was carved by M. Félix Bouré out of 203 different blocks of stone, of which the smallest contained 1·5 c. metres (53 c. ft.). The total content of the statue is 350 c. metres (12,360 c. ft.), and its weight 300,000 kg. (300 tons).

NOTES ON THE TRADE OF ANTWERP.

(Prepared under the superintendence of M. G. A. ROYERS, of Antwerp.)

The commercial greatness of Antwerp dates from the fifteenth century, and culminated during the first year of the reign of Philip II. At this time the population was about 200,000, and as many as 2500 ships might be seen lying in the Scheldt at one time. A single tide would sometimes bring 400 vessels into the port, and each week there arrived about 1000 wagons loaded with merchandise from Germany, the Hanseatic towns, Lorraine, and France; as well as 10,000 country carts bringing provisions, &c. In the wars of the Reformation however Antwerp suffered more than any other town, and was completely ruined. In 1589 the population was only 55,000, and during the seventeenth century it fell to 40,000.

It was not until the Treaty of The Hague, in 1795, made navigation free on the Scheldt that the city began to recover from its long decline; and it was the period of the Consulate and Empire which established the regeneration of the port. Antwerp then became a great maritime arsenal and dockyard, in which was to be constructed the fleet destined for the invasion of England. The fall of Napoleon put a stop to these vast undertakings; and between 1815 and 1820 the docks and quays were handed over by the Government to the town, and became its sole property. The expenses thereby incurred were met by the establishment of port dues. From that time the development of the port has been rapid and immense.

Docks.—The new docks, &c., which this development has necessitated, are described in the special paper by M. Royers (*ante*, p. 494). A few words may however be devoted to the commercial progress of the town. The following Table A gives the tonnage

arriving at the port in successive years, and also the traffic in the goods stations.

TABLE A.

Year.	Vessels Arriving.		Traffic in Goods Stations.		
	No.	Tonnage.	Departure.	Arrival.	Total.
		Tonnes.	Tonnes.	Tonnes.	Tonnes.
1870	4122	1,386,833	616,470	351,604	968,074
1871	5164	1,824,115	818,009	365,056	1,183,065
1872	4193	1,641,653	769,951	444,729	1,214,680
1873	4797	2,062,236	910,641	383,214	1,293,855
1874	4547	2,134,162	945,573	599,035	1,544,608
1875	4351	2,185,416	902,192	746,656	1,648,848
1876	4550	2,527,679	1,112,079	726,173	1,838,252
1877	4457	2,499,482	1,072,137	865,109	1,937,246
1878	4583	2,779,956	1,208,994	827,796	2,036,790

It will be seen that both the tonnage and traffic doubled themselves in the interval between 1870 and 1878. During the same period the estimated amount of money passing in commercial transactions rose from 1,742,000,000 fr. in 1870 to 2,807,000,000 fr. in 1877; and this in spite of the commercial crisis which occurred in the interval.

In addition to the ocean trade, there is a very large trade carried on by barges through the various canals which have their outlet at Antwerp. In 1878 the total of this trade was represented by 32,181 barges, with a gross tonnage of 1,512,039 tonnes.

It may be interesting to compare the traffic of Antwerp with other ports. For this purpose the following Table B will be sufficient, although it is possible that the figures given may not represent quite the same elements for the different ports.

Whilst the position of Antwerp as regards trade is thus shown to be second to none on the Continent, the accommodation for it remains

TABLE B.

No.	Ports.	No. of Vessels.	Tonnage.	Mean tonnage per vessel.
			Tons.	Tons.
1	Antwerp . .	4550	2,221,000	546
2	London . .	11601	5,200,000	447
3	Liverpool . .	5381	4,332,000	821
4	Hamburg . .	5260	2,182,000	399
5	Newcastle and Shields .	6537	2,176,000	328
6	Marseilles .	5345	2,044,000	382
7	Hull . . .	3469	1,512,000	436
8	Hâvre . . .	2922	1,482,000	532
9	Rotterdam .	3443	1,383,000	401
10	Cardiff . .	3047	1,146,000	376
11	Southampton .	1830	744,000	406
12	Bordeaux . .	1677	719,000	428
13	Bremen . .	2046	612,000	299
14	Dunkirk . .	2206	592,000	269
15	Glasgow . .	825	547,000	662
16	Boulogne . .	1775	398,000	224
17	Amsterdam .	1171	386,000	329

very insufficient. In 1876 the relation of the tonnage to the length of quay was 300 tonnes per metre (say 270 tons per yard), which is about four times as great as it is at Liverpool. Despite the use of hydraulic cranes, and of special appliances for towage in the basins, for loading of grain, &c., the block in the traffic is great, and not merely are the present extensions urgently required, but still further increase will probably be demanded ere long.

Stations.—Until recently the only railway station in Antwerp was the Eastern or Borgerhout Station, together with some goods sheds on the north and east of the great docks. In 1871 a contract was made with the government for a large extension of railways, which is now completed. The Eastern Station is now reserved entirely for

passenger traffic, and for what may be termed express goods traffic, such as the carrying of cattle, parcels, &c. It contains two running sheds, one for the Grand Central, and the other for the State Railways of Belgium. In the Eastern Station are pumps lifting the water of the Herenthals Canal to a large tank, which also supplies the station at the docks, the water found at the latter being of too hard a character.

At the docks are two separate depots. The first, called the Stuyvenberg Station, is exclusively for goods traffic, and also contains a repairing shop for locomotives, lighted by Siemens electric lamps. At this station the goods trains are made up, and all the slow-speed traffic arranged. Immediately beyond it is the principal dock station (Station Principale), which serves for the classification and marshalling of wagons on their arrival, and the arranging of wagons which are going to or coming from the sidings on the quays. Goods landed or embarked at quays not furnished with sidings are also loaded or unloaded in the station. This takes place in a shed 200 metres by 70 metres (655 ft. by 230 ft.), but traversed by two roads 12 metres wide (40 ft.). Beside these roads are platforms 8 ft. wide, and beyond these are railway sidings. On the platforms are 28 hydraulic cranes of 1 to 2 tons, and in the sidings are 12 capstans and 12 pulleys for hauling the wagons. In this shed 350 wagons can be easily loaded per day. In the open yard are 12 capstans with 26 pulleys, nine 1-ton or 2-ton cranes, four 5-ton cranes, and one 10-ton crane. Within this station is also comprised a repairing shop for wagons, with an area of 1200 sq. metres (12,900 sq. ft.), and capable of accommodating 200 wagons.

The station is furnished with hydraulic machinery upon the system of Sir William Armstrong & Co. The main engine-house has an accumulator weighing 100 tons, worked by a pair of engines in the ordinary manner, and compressing the water to a pressure of 50 atmospheres. From hence the pressure water is conveyed in pipes to the points where it is required. To avoid frost the pipes are buried at a depth of 1·5 metre (5 ft.), and in addition there are at certain points burners, supplied with a mixture of coal gas and air. This water works the hauling capstans within the station, and also

the hydraulic cranes, both those under the station roof and those in the open air.

The Station Aux Bois, close to the dock of the same name, is mainly used for the timber trade.

The total area of these dock stations and their sidings is 50 hectares (123 acres); and they have above 40 kilometres (25 miles) of sidings, capable of taking 6000 wagons. In 1878 the weight of goods forwarded was 1,208,994 tonnes, and of goods received 827,790 tonnes. The number of wagons received was 283,881, and forwarded 285,557. Taking the whole of the stations together, 2366 wagons were handled every 24 hours.

The Southern Station was decided upon in 1874; it occupies an area of 800 metres by 260 metres (2600 ft. by 850 ft.). It is especially intended for the service of the new quay along the Scheldt. The connecting lines divide as they leave the station, and pass respectively over the upper and lower lock of the entrance to the docks for small craft. By this means the traffic will not be interrupted by the opening of the swing-bridge over one or other of these locks. The station will probably be connected with the other side of the Scheldt by a bridge carrying two lines of railway. It is already connected with the main network of railways by a new line passing by Hoboken. It will be brought into direct communication with the Northern Railway of France by a line from Antwerp to Douay, now under construction.

Lastly, the Pays de Waes Station has been placed upon the new quay, and serves as a depot for the railway of the same name, which has its present terminus at the other side of the Scheldt.

Diamond Works.—One of the most remarkable of the industries carried on at Antwerp is the cutting of diamonds. About 300 years ago an Antwerp lapidary discovered the art of cutting the diamond by means of its own dust. Continuing his efforts he soon discovered various ways of arranging the facets so as to reflect the rays of light, and give the well-known diamond lustre. This workman, whose name was Berchem, left numerous pupils, who followed the trade and transmitted the secret to their descendants. Since then diamond-cutting has always existed at Antwerp, though it has passed through

various phases, and at times has almost been extinguished for want of raw material, or from political or financial difficulties. A little before 1869 it seemed to have received its last blow; but shortly afterwards an unexpected discovery restored it to vigour and prosperity. In 1876 the first diamonds arrived from the Cape of Good Hope, and were soon followed by so many others that the workmen who had given up the diamond-cutting trade returned to it with new ardour; the diamonds supplied by the Kimberley mines being sufficient for the whole of their demand. In a short time the number of workmen was doubled or trebled, and they now number from 2000 to 2500. Their wages are extremely high: some of them get 1000 francs per week (£40), or more, and the very poorest receive about 50 francs (£2) per week. This lowest figure would give for 2000 workmen a total weekly wage of £4000; and this total, though a considerable one, is much below the reality. The firm of Kryn-Huybrechts et Fils (to whom this information is due, and who kindly invited the members to visit their works) pay £600 to £800 weekly to the 150 workmen they employ.

A great advantage to the trade has been the application of steam. Previously manual labour was almost exclusively employed in turning the steel plates required to polish the diamonds. This occasioned a great loss both of money and time, the power available being often insufficient for large brilliants.

Since 1870 the progress of the trade has been rapid and without any interruption. It is often alleged that the Cape diamonds cannot be compared with those of India, but those now being cut are in reality far superior to the older diamonds; and the African mines have furnished gèms which, in purity, brilliance, and water, are quite equal to the best diamonds of ancient times. Most of the diamonds are imported through London.

M. Coetermans, who also invited the members to visit his works, has kindly supplied some further information. He employs about 100 workmen, and has eighty grindstones cutting brilliants, roses, and other forms of diamond. They supply the cut diamonds to all parts of the world, including India, for which country the diamonds have to be cut very thick, and placed the reverse way to the ordinary setting, or upside down. The diamonds are cut by

means of a cast-steel horizontal revolving disc, on which is thrown a mixture of fine diamond-dust and oil. The diamond is partly embedded in a mass of lead, fastened to the end of a short bar, and the face standing out is pressed down upon the revolving plate, and slowly ground to a flat surface. No templates are used, and the form given to the stone is wholly due to the correctness of the workman's eye.

Amongst other trades which exist at Antwerp, or in the neighbourhood, may be mentioned the following:—

(1) Brick and tile works, chiefly at Boom and in the neighbourhood. This trade dates back to the fifteenth century, and now employs about 10,000 workmen. The annual output is from 800 to 900 millions of bricks, besides tiles, &c.

(2) The copper works at Hemixem, making copper from pyrites found in the island of Karmö in the south-east of Norway.

(3) The shipyard of the Cockerill Society at Hoboken.

(4) The manure works of Messrs. Ohlendorff at Burght, making what is known as "dissolved guano of Peru."

(5) The Royal Stearine Candle Works at Borgerhout. These works were founded in 1850, and now supply 50,000 packets of candles per day.

(6) Rice mills, of which there are six, making 40 to 50 million kgs. per year.

(7) Distilleries, which are on a large scale, making about 60,000 litres (13,200 gallons) per day.

(8) Sugar refineries, of which there are three, making 10 to 12 million kgs. per year. There are in addition twenty refineries for sugar candy.

(9) Tobacco works, which are considerable, there being about twenty-six works for the manufacture of cigars alone. About 80 million cigars are produced per annum.

(10) Wool-combing works at Merxem, chiefly for the fine wool of South America and Australia.

(11) Sulphur refineries, varnish works, silk works, oil works, &c.

DESCRIPTION OF WORKS, &c., VISITED AT GHENT.

BY M. GALLAND, INGÉNIEUR PROVINCIAL.

FERDINAND LOUSBERGS SOCIETY'S COTTON MILLS.

Managing Director, M. Joseph de Hemptinne.

This important establishment is situated in the centre of the town, and was founded in 1823 by M. Ferdinand Lousbergs, who died in 1859. It was left by him to the children of his sister, Madame de Hemptinne, and was formed by them into a company. The works cover an area of 4 to 5 hectares (10 to 12½ acres), and employ 1800 hands. The motive power is produced—

(1) By a Woolf compound engine with variable expansion and of 1000 HP.

(2) By another pair of engines of the same type of 500 HP.

(3) By a simple engine with variable expansion, of 300 HP.

There is thus a total power of 1800 HP. These engines were all built by MM. Gilain, of Tirlemont, and are fed by fourteen tubular boilers with heaters, working at 4½ atmospheres pressure. The motion is carried to the top of the mill by vertical shafts, each weighing, with their fittings, about 25 tons, and by bevel gear.

These engines together work 70,000 spindles and 1400 looms. The production includes all kinds of cotton goods, such as damask, piqué, satin, counterpanes, &c. The out-put is 33 tons of thread, and 2300 pieces of cotton per week. Among the machines are some built by Platt Bros., of Oldham; Hetherington & Sons, of Manchester; John Dugdale (late Harrison & Sons), of Blackburn; William Smith Bros., of Heywood; Howard & Bullock, of Accrington; and the Phœnix Société, of Ghent, Manager M. Vermandel.

A special point to be noted is the mode of lubrication of the lower end of the upright shafts, and of the foot-step. Formerly

these were lubricated by oil; but great inconvenience resulted from this, and despite the closest watching the oil was occasionally found deficient. In consequence, the friction of the shaft produced heating of the surfaces nearly up to the melting point. The lubricant is now water, according to a happy invention of the Managing Director, M. Joseph de Hemptinne, and all difficulty has disappeared. The process is based upon the principle of the hydraulic press, and consists in raising the upright shaft through a very small distance by the pressure of the water admitted below it; a film of water is thus introduced between the shaft and the pivot. This water is conducted from four bucket and plunger pumps through a pipe of 0·01 m. in diameter (0·4 in.). This pipe is introduced through the footstep, and terminates in an opening 0·1 m. in diameter (4 in.) immediately under the lower end of the shaft, the water pressure being 320 kgs. per square centimetre, or 4500 lbs. per sq. in. The lubrication is continuous, and the water which escapes is collected in a tank, which surrounds the foot-step.

Flax and Tow Mills of the Liève Society.

Managing Director, M. Louis Desmet.

These works occupy 5 hectares (12½ acres) of ground, and employ 1300 men. The motive power is produced by a Corliss beam-engine with one cylinder and with variable expansion. It is of 1200 HP., and was built by M. Van den Kerchove, of Ghent. It works at 4 atmospheres pressure, and actuates 28,000 spindles. It is fed by five boilers, having two heating tubes at the bottom. There are six other boilers, three being in duplicate, for spinning and drying. The motion is transmitted direct by belt and pulley. The output is 15,000 bundles of yarn per week. The machines are built by Messrs. Fairbairn Kennedy & Naylor, of Leeds.

Cotton Spinning Works of M. Jules de Hemptinne.

These works employ 450 men. The motive power is produced by a horizontal engine, with expansion gear on the system of Nolet, of Ghent. It is of 1000 HP., and the pressure is from 4 to 4½

atmospheres. It is fed by three boilers with heating tubes, and one multitubular boiler on the Barbe system. The motion is transmitted by belt and pulley. The spinning mills can produce 66,000 lbs. per week of No. 8 to 10 cotton, and the twist mills 10,000 lbs. A small machine-shop is annexed to the works, where are made cards, drawing frames, bobbin frames, &c. Among the machines are some constructed by Platt Bros., of Oldham; Curtis & Sons, of Manchester; and Lord Bros., of Todmorden. Others are the invention of M. Jules de Hemptinne, the proprietor of the works.

New Dock Works at Ghent.

These works are at present going on under the direction of M. Vanderlinden, Ingénieur des Ponts et Chaussées, at Ghent, who was the originator of the project. The contractors are MM. Willems and Caze. A length of quay-wall of about 750 m. (820 yards) has already been raised to about 1 m. (3¼ feet) above the level of the canal. Six caissons still remain to be sunk.

The outer basin, in course of construction, will connect the Ghent docks with the Ghent-Terneuzen Canal. This basin will have an area of 25 acres, and a minimum depth of 21·3 feet; and two graving-docks will open into it, having lengths of 426 feet and 230 feet respectively. The works comprise the excavation of the outer basin for a length of 1200 yards; the construction of a quay-wall on the right bank of the canal, 3400 feet long, and resting on a foundation whose top is 24½ feet below the water-level of the canal; the erection of 1894 feet of retaining-wall on the two banks; and the formation of a culvert.

The depth to which the foundations of the quay-wall of the basin had to be carried (33 feet below water-level) and the sort of quicksand in which they had to be excavated, led to the adoption of the compressed-air system, similar to that employed at the Antwerp quays. In the first instance, the excavation for the foundations was accomplished for a considerable depth by dredging, the dredged material being conveyed away by means of a pump and floating tubes. As soon as the dredging has been carried to the

desired depth along the site of the quay-wall, the working-chamber caisson, surmounted by removable plate-iron walls serving as a cofferdam, is floated into place between barges carrying a staging, from which it is suspended by chains. The wall is built on the top of the working chamber, within the iron cofferdam, till its weight causes the caisson to rest firmly on the excavated bottom. Compressed air is then introduced into the working chamber, and the workmen descend, through a plate-iron tube resting on the roof of the caisson, and complete the excavation for the foundations. The excavated material is thrown into a box, into which a lift and force pump injects water; and by turning a stop-cock, the mixture of silt and water is driven out by the pressure of air in the chamber through a pipe communicating with the outside. The working chamber is finally filled with concrete through vertical tubes; and as soon as the wall, which has in the meantime been gradually built up, is higher than the water, the iron sides are removed and used for another caisson, and the wall is then raised to its full height. The interval left between each successive caisson is 2 ft. 7½ in., which is filled up with concrete below, and with brickwork above. To ensure the connection of the separate lengths of wall, grooves (1⅓ ft. by 1½ ft.) are formed in the end faces of each length. The contractors have since found it expedient to do less dredging, so as to make the caisson rest on the bottom in a smaller depth of water, which enables them to commence the wall directly on the top of the caisson without the use of the plate-iron sides; moreover the long and difficult operations with the floating stage are dispensed with, and, though the excavation inside the working chamber is increased, there is no danger of dredging to too great a depth.

Nursery Gardens of M. Louis van Houtte.

These gardens, which have been in existence about fifty years, are celebrated throughout the world for their beauty and the care with which they are kept. They occupy 30 hectares (74 acres) and contain fifty conservatories. Plants, shrubs, and trees of all kinds are cultivated, belonging alike to the tropical, temperate, and

arctic zones. The arrangements for watering and heating are of the most complete character. Two sets of water pipes are carried throughout the whole gardens. The first is for watering the plants, and consists of earthenware pipes, which connect 140 wells in cement, scattered throughout the area, and each containing $1\frac{1}{2}$ c. m. (53 cubic feet). These are supplied from a basin, which is itself fed from a tank containing 64 c. m. (2260 cub. ft.). A 4-HP. engine works two double-acting suction and force pumps, which take water from the Scheldt at 700 metres distance (770 yards), and pump it into the tank, which is placed on the top of the engine-house, 5 m. ($16\frac{1}{2}$ ft.) from the ground. The second set of pipes is for warming the conservatories. The mains are of cast iron, 0·15 m. in diameter (6 in.), while the branches which traverse the conservatories are 0·09 m. ($3\frac{1}{2}$ in.). The total length of these pipes is 9000 m. ($5\frac{1}{2}$ miles), and the temperature of the water varies from 60° to 80° C. (140° to 176° F.). It is heated in sixteen boilers with return flues. The number of pipes in each conservatory varies from four to twelve, according to the temperature desired. The number of workmen employed is about two hundred; in addition to whom travellers are always visiting different quarters of the globe, to search for new plants. The firm publish a magnificent work on the hothouse and garden Flora of Europe, of which 23 vols. have already appeared. A number of artists and engravers are always employed in copying new plants and flowers produced in the gardens.

Engine Works of MM. Carels Frères.

These works, founded in 1839, are situated by the side of the docks, and connected with the State Railways at the goods station of Ghent. They cover an area of 11,000 sq. m. ($2\frac{3}{4}$ acres), and employ 400 men. The motive power for the whole works is produced by an engine on the Sulzer system, of 100 HP. The valves are in equilibrium, and the expansion is varied by the governor. There is besides, in the erecting shop, a horizontal engine of 25 HP., also with expansion varied by the governor. This engine is kept in reserve to work the large planing, drilling, and mortising machines

when required. There are also three Brotherhood engines, to work different tools at times when the main engine is stopped. Steam is raised in a boiler with two internal flues and with Galloway tubes, and also in a vertical boiler heated by the waste heat from the heating furnaces. The erecting shop, foundry, and forge are lighted by sixteen Jablockhoff lamps, worked by a Gramme dynamo-electric machine and by an exciting machine, having together a power of 17 HP. In the shops are a 1-ton and a ½-ton steam-hammer, and a spring-hammer worked by belt and pulley. The smiths' hearths are blown by a fan by MM. Sulzer Bros., of Winterthur, Switzerland. The foundry has two cupolas, blown by a fan on the same system, which are capable of running castings of considerable size. The small castings, and the articles in copper for the locomotive engines, are moulded by the Sebold and Neff moulding machine, and there is also a machine for sand-moulding by the same makers. The tools in the fitting shop are by Belgian, English, and German makers. Among others may be noticed a large double planing machine on the duplex system, planing four faces, and capable of planing 7 m. × 2 m. × 2 m. (23 ft. × 6½ ft. × 6½ ft.). There is also a large double boring machine on the Daverio system; and a double slotting and drilling machine, chiefly used for shaping locomotive-engine frames, and built by Collier and Co., of Salford, Manchester. There is also a double mortising and drilling machine, principally used for cutting the frames of locomotives, and a large boring machine for boring the frames of Sulzer engines. There is a 5-ton radial crane and also a 10-ton travelling crane in the erecting shop. In the locomotive shop there is a 20-ton travelling crane, and in the foundry a 12-ton radial crane, and a 10-ton travelling crane.

The firm builds horizontal steam engines, especially engines on the Sulzer system with equilibrium valves, and also railway and tramway locomotives. The output yearly is about 20 Sulzer engines, and 40 to 50 locomotives. The boilers come from the Société de Chaudronnerie et Fonderie Liégeoises, of Liége, of which M. Gustave Carels is President.

DESCRIPTION OF THE MARIEMONT AND BASCOUP COLLIERIES.

(PREPARED UNDER THE SUPERINTENDENCE OF THE MANAGING DIRECTOR, M. L. GUINOTTE.)

I. GENERAL DESCRIPTION. (*See* Map, Plate 54.)

These two collieries, whilst completely distinct as to working and management, are united under a single head office. The former owns a royalty of 1480 hectares (3650 acres), the latter of 2410 hectares (5950 acres); making a total of 3890 hectares (9600 acres). The number of workable seams of coal is seventeen, varying in thickness from 0·40 m. to 1·70 m. (1·31 ft. to 5·57 ft.) The coal is specially suited for steam raising and for household purposes. The total out-put is about 1,000,000 tons per annum, divided equally between the two collieries. There are ten pits in the Mariemont, four in the Bascoup colliery. Many improvements in coal working have been invented or adopted at these collieries, of some of which a brief account will be found below.

The central office of the two Societies, as well as the special office of the Mariemont colliery, is situated at Mariemont; the special office of the Bascoup colliery is at Bascoup. The two are united by telegraph and telephone. In collieries of such extent as these the multiplicity of workings adds considerably to the cost of management, and also renders difficult the mixture of coal which is often required by the purchaser. The Society have solved this problem by forming a central establishment called the Triage Central, for screening, loading, and despatching. To this centre all the pits send their out-put by means of a system of endless-chain haulage. With the same point are also connected the repairing shops and stores of all descriptions. This establishment was erected in 1873. The system of endless-chain haulage, though known for many years

about Burnley and elsewhere, and largely used on the Continent, has nowhere been applied on so large a scale as here. It consists simply of an endless chain lying on the wagons, and passing at one of its extremities round a driving pulley, and at the other round a return pulley. Originally the driving pulleys were of cast iron, with recesses in the circumference to fit the links of the chain. This system had serious disadvantages. As the chain lengthened in work, its links no longer fitted into the recesses; hence arose slipping, violent shocks, and rapid wear both of the chain and of the pulley. M. Briart has completely remedied this by screwing into the rim of the pulley moveable steel grips, the position of which can be altered by a turn of the screw so as to suit the lengthening of the links.

The establishment of this automatic haulage necessitated the installation of a complete plant for emptying and classifying the coal, and for loading it on trucks, giving it at the same time a thorough cleaning.

Classifying has been carried out by the employment of screens with moveable gratings, invented by M. Briart. Every system of screening must satisfy the following main conditions:—

(1) The different sizes of coal must be completely separated.

(2) The coal must be preserved from breakage.

(3) The work must be rapid and cheap.

Ordinary fixed screens placed at an angle may satisfy some of these conditions, but not all. If the angle is low, the coal does not break, but the separation requires a considerable amount of manual labour. The work is also slow, and the screens, if the out-put is large, must be very numerous. If the angle is high, the coal falls more rapidly, but it thus gets broken, and the proportion of large coal and rough slack is diminished. Moreover the separation is imperfect.

Various systems of screening have been invented to overcome these difficulties. In England and Germany cylindrical screens are largely employed. They work well as to separation and rapidity, but if the coal is friable the breakage is large. M. Briart has adopted another principle, which prevents any breakage, whilst

effecting the complete separation of the different sizes, and largely diminishing the manual labour. The apparatus consists of one or more gratings placed at a slight inclination one above the other, and working in the same way. Each is formed by a row of fixed bars and a row of moveable bars, which when at rest lie in the same plane. The moveable bars are fixed lengthways in a frame, which at its lower extremity is carried on two cranks, and at its upper extremity on two eccentrics keyed upon a rotating shaft. The moveable bars are above the fixed bars during one semi-revolution and below it during the other. During the former they have a longitudinal motion downhill, during the latter a similar motion uphill. Hence, when a coal wagon is emptied upon the upper part of the screen, the coal is first lifted by the moveable bars and carried downwards; it then rests on the fixed bars during the lower semi-revolution. At each revolution the coal is thus shaken up throughout its mass and gradually screened. All the small coal falls through the spaces between the bars, whilst the large coal is brought to the bottom without any shock, by a succession of steps. If necessary, both sets of bars can be made moveable.

If there are to be three classes of coal, two screens will be required. The first separates the large coal from the rough slack; the latter, which falls through, is received upon a frame which carries it upwards to the top of the lower screen, and on this it is separated into rough slack and fine slack. This lower screen may be placed horizontally, which enables the height of the discharging road above the rails of the delivery road to be lessened. This height has been fixed at 6 metres (19·7 ft.).

Experiments made on coal screened by the old and the new method have given the following results:—

	Mechanical Screening. Per cent.	Hand Screening. Per cent.
Large coal	16·35	13·15
Rough slack	32·63	31·08
Together	48·98	44·23
Fine slack	51·02	55·77
Total	100·00	100·00

In the more recent examples, by simply turning a handle, without stopping the apparatus, it is possible to vary the distance between the bars of the screens, so as to alter the character of the screening. There are also mechanical means for cleaning the coal, and for delivering the screened coal into wagons without its falling from any height. The yield is thus increased, and the manual labour much diminished.

The screening shops, of which there are three, are all on the same plan. They are large rectangular buildings of three stories. The ground floor is on the level of the railway; the first floor contains the screens and loading apparatus; and the second floor the apparatus for emptying the trucks. The appliances for classifying the coal are placed at the two sides. They consist of turn-tables, or traversers, which bring the screened coal from under the screens to be cleaned by hand. From these the coal is carried to the railway wagons by special apparatus.

The trams from the pit are brought by the endless chain to a set of sidings on the uppermost floor of the shop. Each siding ends in a tipping cradle or "culbuteur," placed above one of the screens. This consists of two rings tied together by cross pieces and resting on four pulleys. The tram enters at one end and goes out at the other. Whilst in the cradle it is turned over sideways, and empties its load without shock upon a circular table which spreads the coal over the full width of the screen. The trams on leaving the tipper are carried forward by endless chains worked by the main engine to sidings running on each side of the building; by these they are returned to the yard at which they arrived, and so to the mine. The railway wagons which receive the coal stand on the platform of a weighing machine, so that the weight is known as soon as the wagon is filled.

The system of tramways which connects the various pits with the screening shops is connected by means of the winding engines with a similar system underground, also worked on the endless-chain principle. This underground chain system has a length of more than 9 kilometres on the whole (5·6 miles). Three methods have been used for working the chains. The first consists of a small steam

engine and boiler placed inside the mine. In the second, motion is transmitted from above ground by an endless rope, passing over a pulley at the surface, worked by a steam engine, and going down the shaft. At the bottom this rope passes round another pulley, and drives, through a second pulley keyed upon the same shaft, the underground hauling chain. In the third or automatic system, the full trams are brought down to a level below that at which the coal is got, and the power given by their descent is used for haulage on the horizontal roads. Inclined planes are provided, down which the full trams run; and the energy thus obtained is sufficient not only to draw up the empty trams, but to propel the full trams along the level road as far as required. The work of hauling is really done by the winding engine, which has to raise the coal from a greater depth.

All the underground roads are on iron cross sleepers of the Legrand system. The trams contain 5 hectolitres ($17\frac{1}{2}$ cub. ft.); they are built entirely of steel, and are supplied with grease boxes on the Koepe system.

The total power used in the two collieries is not less than 5200 H.P., produced by 111 boilers, and utilised by 78 engines, stationary or locomotive. A special department, called the Division du Matériel, looks after the whole organisation, commercial and industrial, both as regards the workmen employed and outside customers. There is a special office for design and experimenting, in which all the apparatus, &c., is designed in full detail; the contractors having nothing beyond the task of construction.

The chief matters of interest at the pits are as follows:—

(1) The ascent and descent of the workmen, which is carried on by means of a man-engine or Fahrkunst. This is worked by means of a hydraulic balance invented by M. Abel Warocqué. It has a stroke of 3 m. (9·84 ft.). The platforms on each rod are 6 m. apart (19·7 ft.), and the speed is 8 strokes per minute. The speed of ascent is thus 24 m. per minute ($78\frac{3}{4}$ ft.), so that it requires 20 minutes to ascend or descend through 500 m. As this speed is somewhat slow, a special improved apparatus has been erected at No. 5 pit.

(2) The winding engines are all provided with the variable

expansion gear of M. Guinotte. This consists of two valves, one on the back of the other, as in the Meyer system, but the expansion valve is a simple slide fixed to the valve-rod. The variation in the expansion is given by varying the radius and angle at which the eccentric is set upon the shaft; and it is obtained by means of a link-block moving in a link, which is worked by two eccentrics. The different positions of the link-block correspond to different degrees of expansion.

When this system is applied to engines running both ways, the link is worked by a single eccentric set suitably for either direction, and the second eccentric is replaced by a motion regulated by the valve-rod of the main valve. For winding engines the link-block is worked by a special gear, which varies the expansion in accordance with the variation of the resistance. In several of the winding engines the reversal of the valves is effected by means of the special steam-gear called the *Servo-Moteur*.

(3) The guides within the shaft, as lately re-constructed, consist of Vignoles rails, which are placed in pairs and fixed to a series of girder irons placed one above the other across the centre of the shaft. This system is found to give much fewer accidents and to cost much less in maintenance than the old guides of wood.

The above is only one example of the substitution of iron for wood. Amongst others may be mentioned sleepers on the underground roads, pulley frames, and ventilating doors. Steel ropes have also replaced, in recent instances, the ropes of aloe fibre previously in use. In most of the pits the cage, after coming to the top, is received upon a balanced platform of two stories, the lower of which is already loaded with return trams. The weight of the cage causes the platform to descend and brings the cage down to the discharging level.

(4) The pumping engines are not remarkable, except in the case of pit No. 5, described below.

(5) The ventilators, ten in number, are all on the Guibal system, generally 9 m. in diameter and 2 m. wide (29·5 ft. and 6·6 ft.). Three pits possess two fans, to provide for possible accidents.

A special apparatus, due to M. Briart, and known as the Clapet d'Aérage, allows two of the winding pits to be used as upcast shafts

for the purpose of ventilation. It consists of a strong wooden partition fixed immediately below the reception platform, and of a depth somewhat greater than that of the cage. The pit is thus divided into two compartments, just large enough to receive the cages. The cages form, as it were, pistons in these two compartments; and whilst they are in them, the entry of external air into the shaft is almost completely cut off. At the receiving platform there are two traps, or moveable covers, which, when the cages are in the shaft, lie over the pit and prevent the entry of air. The ropes of the winding engine pass through holes in them. These covers are raised in guides by the cages when they reach the top, and are left behind on the top of the shaft when the cages descend. Below the partition is an air-drift communicating with the ventilator. By this arrangement it will be seen that the shaft is always closed either by the cages or by the covers, so that the external air cannot enter, and the ventilator can only draw the air from the mine. The closing of the pit is not of course absolutely complete, but the air which enters through the holes left for the ropes, &c., is insignificant in quantity. This system has worked well for more than fifteen years.

The timber employed underground is always ordered to definite dimensions, which are always kept in stock, so that exactly the quantity necessary can always be supplied. This system is found to offer great advantages in the way of economy.

There is a complete railway system worked in common by the two collieries, which conveys the out-put to the station at Bascoup-Chapelle. It is worked by five main-line engines and five shunting engines. There is also a wharf at Bellecourt and another at Mons. To unload the coal at these wharves, it is conveyed in sheet-iron wagons, each consisting of five rectangular boxes placed side by side. These boxes can turn on a hinge at one side, and are lifted at the other side by means of a small steam-crane. The side next the hinge opens from the bottom on withdrawing two bolts, and by tipping each box in succession its load is discharged through a hopper into a barge. By this arrangement a barge of from 60 to 70 tons can be loaded in less than half an hour.

For carrying coke and patent fuel, hopper wagons are employed. They are of sheet iron, and comprise three hoppers square at the bottom, with openings below the frame. The bottoms are closed by covers, which can be withdrawn by a rack. The wagon is covered at the top to protect the contents from wet. It has a special coupling, which enables the wagons to be coupled without the workmen passing between them. This system is due to M. E. Peny and to M. Mabille.

II. Mariemont Colliery.

This colliery has a royalty of 1480 hectares (3660 acres), partly within the Forest of Mariemont. There are eighteen seams of coal. They lie with a tolerably regular dip towards the south, and are worked by various methods according to circumstances. The out-put is about 500,000 tons per annum from six pits, the amount varying between 522 tons per day at the St. Arthur pit, and 100 tons per day at the Le Placard pit. The situation of the pits is shown on the map, Plate 54.

The endless-chain haulage system, which connects all these six pits with the Triage Central, has a total length of more than 5300 metres (3·3 miles); it is likewise shown on the map. The district is much cut up by roads and railways, which presented considerable obstacles in the laying out of the haulage system; on the other hand, the whole of the surface is the property of the Society. Amongst the principal works of the system may be mentioned a tunnel 107 metres long (117 yards), by which the haulage road passes under the railway from Baume to Marchienne; and another tunnel of 72 metres (79 yards), passing under the Montaigu Road. These tunnels are circular in section, of 2·75 metres diameter (9 ft.). There is also an iron suspension bridge, by which the Placard section is carried across the boilers, sidings, &c., at the Triage workshops, and over a road. It consists of two suspension spans of 36·20 and 37·30 metres (119 and 122 ft.), and of two fixed spans of 12 and 20·50 metres (39 and 67 ft.).

The Triage workshops just mentioned have been described in the first section. The coal-washing apparatus is on the system of

Lührig and Coppée, the same as at No. 5 pit described below. The patent-fuel works, which are adjacent, are arranged to yield 250 tons of fuel bricks per day: the system is that of M. Bouriez with some modifications. The coal comes to them still wet from the washers, and comprises nothing but fine slack below 5 mm. diameter. It is raised by a Jacob's ladder, and deposited on a band of sheet-iron plates, inclined at 20°, which carries it slowly to a wooden tower divided into six compartments and capable of containing 200 tons. From the tower it is delivered by screw distributors to six hydro-extractors on the system of M. Briart. This hydro-extractor has its axis horizontal, and has the usual screw for the delivery of the coal; but the water escapes through a narrow slit, extending the whole way round the extractor. The coal falls into a conical drum, with steep sides, and slips down into a second cone, containing the regulating screw; a second drum, revolving at a different speed, receives it from the screw, and delivers it at the circumference, whilst the water escapes by the opening between the two drums. The difference in speed always keeps this opening clear. The machine can be so regulated as to dry slack of any size at will.

From the hydro-extractors the coal passes to a dryer, consisting of a sheet-iron cylinder, having fixed plates riveted on the inside, and each occupying a quarter of its section. The coal falls from one plate to the next below, being swept off each by rakes revolving on a central axis at 50 revolutions per minute. The coal is thus mixed up and falls as dust into the smoke coming from a furnace placed below the dryer. This smoke dries the coal whilst gradually getting moistened itself.

From the dryer the coal passes to the hydraulic presses, which have an improvement due to M. Guinotte. Between the compressing pistons and the cranks which work them are placed two hydraulic cylinders communicating with each other; in these the pressure is maintained constant by means of a loaded plunger. The result is that the cranks are double-acting, instead of single-acting as in the ordinary presses.

The steam-engines working the washers and pressers have a variable expansion on the Guinotte system. The governor acts

on the expansion valve through a simple mechanism called the *Servo-moteur cinématique*. This system solves the problem of applying the governor to give any required grade of expansion with as great regularity as in a Corliss engine.

Close to the Triage works is the store for bricks, mortar, &c., together with brick-making machines and mortar mixers.

The St. Arthur pit is the most important of those in the Mariemont Colliery. Its daily out-put is from 500 to 600 tons. There is a winding engine of 200 HP., a pumping engine of 600 HP., a man-engine of 110 HP., and a Guibal fan of 9 metres diameter (29½ ft.). It comprises three shafts all in brickwork. Of these the first is a winding shaft in two compartments, 510 metres deep (1673 ft.); the second is a similar shaft, which is used both for winding and for the ascent and descent of the workmen; the third is an upcast shaft 386 m. deep (1266 ft.) and 2·40 m. in diameter (7·87 ft.). As explained in the first section, the whole of the coal is wound from the lowest level, at 476 m. (1561 ft.), although two higher levels are worked; from these the coal runs on inclined planes down to the lowest level. At the mouth of the pit are a number of large rooms warmed by stoves, and containing chests in which the men can keep their tools and clothes. The other pits belonging to the colliery are the St. Henriette pit (of which the arrangements much resemble those of the St. Arthur pit), Réunion, Abel, L'Étoile, and Le Placard pit. The last is the only pit belonging to the Society where the men are raised and lowered in cages.

III. Bascoup Colliery.

This colliery has a royalty of 2410 hectares (5955 acres), lying to the west of the Mariemont Colliery. The out-put is 500,000 tons per annum; of which about one-half comes from pit No. 5, which lies apart from the others. This pit delivers 800 to 1000 tons per day. It comprises a winding engine of 150 HP., two pumping engines of 400 HP., a man-engine of 40 HP., and two Guibal fans of 9 metres (29½ ft.) diameter. There are also twelve boilers, warmed rooms for the men, screening shop, and coal-washing apparatus. There are

three circular shafts; of which the first is 4·25 metres diameter (14 ft.), and is used for pumping and for the men; the second of the same diameter is used for winding, and the third of 3 metres diameter (10 ft.) is used for ventilation. The third pit can however be utilised for winding, if required, by closing its mouth with covers, in the manner described in page 576. In all these pits it was necessary to sink, close to the surface, through a layer of sand about 30 metres thick (100 ft.), filled with water. This was done by the pressure process, a column of cast-iron tubbing being driven right through the sand by means of screw presses until it penetrated about 1 metre into the coal-measures. This column was formed of whole rings, turned and bolted to each other, as in the Chaudron system; and at the bottom were cutting edges, which excavated to a diameter 0·25 m. (10 in.) greater than that of the finished pit. There were eight screw presses bearing against a solid scaffold erected above the shaft, and supporting the different tools required for the sinking. It was also loaded by pig iron to a weight amounting, towards the end of the operation, to 450 tons. The tubbing was sunk direct into a seam of coal of great thickness; and as this was very unfavourable for closing the tubbing in the open air, compressed air was employed, and succeeded perfectly. From thence the shafts were sunk to the depth of 95 m. (312 ft.), all below the tubbing being bricked.

The great quantity of water which was expected induced the Society to provide two pumping engines, which with other motors are placed in the engine house. The two engines together deliver half a cubic metre per stroke, or, at the ordinary speed of 10 strokes per minute, a total of 6000 cb. m. in 10 hours (212,200 c. ft.). They are rotary engines with a high grade of expansion, cutting off at not later than one-tenth of the stroke; but each has only one cylinder, as M. Guinotte considers, contrary to the common opinion, that the compound system is not the most advantageous for such engines. The pumps are so arranged that the main rod always works in tension, the plunger being fixed while the pump barrel moves. The main rod consists of a single round bar of iron, going the whole depth of the pit, and not requiring any guides. There are three lifts of pumps, the height of each being 80 to 85 m. (260

to 280 ft.) The rod is attached direct to one end of the engine-beam, the other end of which is worked by the steam cylinder. From the piston-rod is hung through links a counterweight, which allows the cylinder to be double-acting whilst the pumps are single-acting. The foundations consist of an immense bed-plate of cast iron, 5 m. in height (16·4 ft.), and are much more solid than if built either of brickwork or of masonry. The advantages of the arrangement are the following. First, the beam is always subjected to the same stress, namely that due to the main rod itself, and to the column of water raised. This stress is always in the same direction, whether on the ascending or descending stroke, so that the beam is protected from that reversal of strains which so often produces the deterioration and final rupture of such structures. Secondly, the rods connecting the piston to the beam are under the same conditions as the beam itself. Thirdly, the whole pressure exerted by the steam on the piston is subdivided into three portions: one is passed to the beam through one set of rods, another to the fly-wheels through a second set of rods, and a third to the counterweight through the links. Each of these connections has only a moderate strain to support, the full strain coming upon the piston-rod alone. The distribution of steam is by means of piston slide-valves, and the expansion is on the system of M. Guinotte.

The man-engine is on the system of M. Warocqué, but with special improvements by M. Guinotte. The objections to the former system were as follows:—

I. The stroke was necessarily small, and the number of strokes per minute was limited by the necessity of preventing any shock at the beginning or end; hence the speed of ascent or descent was slow.

II. The steam was always acting at full pressure, and the waste of fuel was therefore large.

III. The valves were worked by the engine-man; hence the stop at the end of each stroke was not always exactly the same, and any inattention on his part might produce too sudden starting and stopping: this was another reason why the speed had to be slow.

These objections are all remedied in the present man-engine. The rods with their platforms are, as before, suspended from two plungers always in hydraulic balance: but equilibrium is obtained, not by a direct communication between the two cylinders, but by an intermediate crank-shaft, to which the plungers of two pumps are connected. Each of these pumps communicates with one of the cylinders of the hydraulic balance, and the cranks are so arranged that one pump is delivering into the balance at the time that the other is drawing from it. Since the strokes of the pistons in the pumps and in the hydraulic balance are inversely proportional to their areas, a crank of ordinary throw suffices to give a long stroke to the rods. Here the effective stroke of the rods is 5 m. (16·4 ft.), while the cranks have a radius of only $\frac{3}{4}$ m. ($2\frac{1}{2}$ ft.). The pumps are worked by an ordinary rotary engine making 10 revolutions per minute; the pump shaft makes only 1 revolution per minute, being connected by gearing. This engine has the Guinotte system of variable expansion worked by the governor.

The speed of ascent and descent has by this means been doubled, whilst at the same time the men have ample time for stepping across from one platform to the other. No unpleasantness results to the men, because the rods move as if actuated direct from the cranks, and therefore the speed becomes considerably slower at the dead points—that is at the starting and stopping. Moreover the platforms always come exactly opposite each other, so that the men pass across readily from one to the other. The steam consumed is much reduced by the employment of expansion; the saving is estimated at 75 per cent. A similar man-engine is in course of erection at the Réunion pit, with a stroke of 6 metres (19·7 ft.).

There is a steam capstan, which calls for no special remark beyond mention of the dead-weight brake which it carries, and an arrangement which allows the overhead pulleys to be shifted so as to serve one or other of the three compartments in the pit. The winding engine is a vertical two-cylinder engine, with automatic variation of expansion and with a steam-brake. It works a round steel rope wound upon cylindrical drums: the overhead pulleys are of wrought iron and consequently very light: the guides in the shaft are of iron.

The underground haulage deserves special mention; the principle is the same as in the other pits, but the arrangements are much simplified. On each side of the shaft at the level of 240 metres (262 yards) a chamber is excavated for loading the trams into the cages. From each of these chambers start two rising inclines, each with a single track, one towards the north and the other towards the south. The two northern inclines meet at a point situated at the level of 150 metres (164 yards), and the two southern inclines also meet at the same level. At these two points of meeting are placed the motor pulleys of the automatic haulage. These points are on the line of the main hauling roads which run east and west from each of the motor pulleys. The self-acting inclines to the shaft are worked by two endless chains passing round the semi-circumference of the motor pulleys: the full trams descending on the one side, and the empty trams ascending on the other. The chains pass round return-sheaves placed at the two extremities of the chambers above mentioned, and cross the shaft without interfering with the cages or with any of the operations within it. The length of the northern system is 1300 m. (1420 yards), and of the southern system 490 m. (535 yards.)

The screening shop at No. 5 pit comprises three sets of apparatus: one is a revolving circular table carrying a grating, the two others are on the same plan as those at Mariemont, and separate the coal into five classes. They have a special arrangement which allows the distance between the bars to be altered, and are so placed that the similar products coming from the two sets of apparatus can be brought together. The finest coal goes to the washing machine; the other classes are taken direct to the wagons on moving bands, the cleaning being done by hand as they go. Each apparatus is able to screen 120 tons per hour. At times of pressure this single pit has furnished in one day as much as 2100 tons, with one set of screening apparatus only.

The coal-washing apparatus is on the system of Lührig and Coppée.* The small coal is raised in a Jacob's ladder, and thrown

* See Paper on Coal-Washing, Proc. Inst. C.E., vol. lxx., p. 134.

on a perforated iron table, which is shaken violently, and so subdivides the coal into four classes of different sizes. The first two of these are washed in ordinary tanks, the others on the felspar screens of the Lührig system. After washing, they are brought together again and delivered as one lot. The finest dust is sometimes delivered separately. The yield of the washing apparatus is 40 tons per hour.

The other pits of the Bascoup Colliery are the St. Catherine, No. 3, and No. 4. The number of seams worked is sixteen. There is an automatic haulage system leading from each pit to the Atelier Central de Triage at Bascoup, and comprising a tunnel 272 m. long (297 yards), which passes under the workmen's village at St. Catherine. The water from above the 210 m. level is collected and carried in a tunnel driven for the purpose to No. 5 pit, where it is pumped. The water from the lower levels is pumped from No. 4 pit. The Atelier Central de Triage has six sets of screening apparatus, and is lighted by Gramme arc-lights outside, and by Edison incandescent lights inside. If this lighting is successful it will be extended to the other establishments.

IV. Workmen's Institutions.

These collieries have for a long time made a special study of the material, intellectual, and moral welfare of the numerous workmen whom they employ. In 1872 was founded, by the late M. Arthur Warocqué, the Industrial School at Morlanwelz. This school has now more than 350 scholars, who receive free education, comprising mathematics, drawing, mechanics, physics, mining, &c. The courses of lectures are given by the engineers of the collieries, and the certificates conferred by the school are highly appreciated by the workmen. The Societies have also organised a sanitary service, and have done their utmost to encourage the formation of school-clubs and of co-operative stores. The sanitary service is under the direction of a committee composed of delegates from the management, from the medical men, and from the workmen. There is a special benevolent fund belonging to these collieries, which in 1882

distributed to sick or injured workmen a total sum of 40,710 francs. The co-operative stores and the workmen's benefit club are not confined to these collieries alone, but are absolutely free; each being managed by a committee appointed by the shareholders. In addition, a large number of saving clubs exist in the collieries, and are worked entirely by the men themselves. There is a pension fund established on the same basis as the State pension funds, and managed by a Committee composed of members of the colliery staff.

With regard to workmen's dwellings, the Societies have given all possible encouragement to the purchase of land and building of houses by the workmen themselves; giving them for this purpose advances of money without interest, and repayable upon easy terms. They have also built numerous houses, large and convenient, which they let at very reduced prices. The success of these endeavours is shown by the fact that 22 per cent. of the adult workmen are now proprietors of the houses they occupy. The Society of Mariemont owns 280 houses for workmen, and the Society of Bascoup 270, containing together a population of 3000 souls. Each house consists of a large living-room with a kitchen and a bedroom on the ground-floor, two bedrooms on the first floor, and some out-buildings. They are scattered in groups of two, four, or six, and do not take the form of a town, for which the workman often evinces a certain repugnance. Each house has its own garden, which the tenant keeps with the greatest possible care. They are all lighted by gas, the cost of fittings being borne by the Society. The employment of women underground was some years ago put an end to by the Society, without waiting for a law on the subject.

The General Manager is M. Lucien Guinotte, the Mining Engineer M. Briart, the Mechanical Engineer M. Weiler, and the Locomotive Engineer and General Secretary M. Peny.

NOTES ON BELGIAN RAILWAYS.

BY M. PAUL TRASENSTER, OF LIÉGE.

The law authorising the first Belgian railways was passed on 1st May, 1834. They were, excepting some lines in France, the first on the Continent. Two great lines were sanctioned: the one running north and south, from Antwerp through Malines and Brussels to Mons; the other east and west, from Ostend, through Bruges, Ghent, Malines, Louvain, Liége, and Verviers, to Herbesthal.

The first line was opened on 5th May, 1835, from Brussels to Malines, a length of 20,395 metres (12·6 miles). The following figures show the further development of the Belgian railways.

31st Dec.	1840.—	State lines,	333·8	kil.	Companies' lines,	32·3	kil.
„	1850.—	„	624	„	„	273	„
„	1860.—	„	748	„	„	980	„
„	1870.—	„	868	„	„	2028*	„
„	1881.—	„	2888	„	„	1294	„

Of the total 4182 kilom., 1154 kilom. were built by the State, 1409 kilom. built by Companies and bought afterwards by the Government; and 325 kilom. were built by Companies and bought by the State, but with an annual sum still to be paid to the Companies.

Belgium has more railways than any other country compared with its area. Per 1000 square kilom. there are 138 kilom. of railway in Belgium, 92 in Great Britain, 62 in Germany, 48 in France, and 16 in the United States.

The rates of transport are very low, on account of the Government being continually urged to lower them. It is an admitted principle that the charge for conveyance should be exactly equal to the cost, without any profit for the State. It is even open to discussion whether

* Between 1870 and 1880 many lines were bought by the State.

the charge should include the gradual extinction of the capital, as the Minister of Finance wishes it to do.

The fares are as follows for ordinary trains:—1st class 1·18*d.*, 2nd class 0·88*d.*, 3rd class 0·59*d.* per mile. For express trains add 25 per cent. to the fare for ordinary trains. Return tickets, issued for two days when the distance is over 75 kilomètres (45 miles), for one day when less, are 20 per cent. less than the price of two single tickets.

There are special low fares for certain classes of travellers, e.g. students and workmen, 0·185*d.* per mile; commercial travellers, 0·28*d.* per mile.

Goods are divided, for freight purposes, into four classes.

Class IV. contains heavy goods,—stone, pig iron, coal, iron ore, &c.

Class III. contains more valuable goods,—iron and steel, rails, plates, bars, tyres, locomotives, grain, &c.

Classes I. and II. take manufactured goods: textile manufactures, engines and tools, for instance, are in the first class; zinc, copper, lead, wool, cotton are in the second.

The rate of freight diminishes proportionately with the distance, by the following formula:—Freight $= f$ (constant) $+ na + n'a' + \ldots$ Here $n\ n' \ldots$ are different numbers of kilomètres, $a\ a' \ldots$ are numbers of francs per tonne-kilomètre. These numbers are as below:—

	f	n	a	n'	a'	n''	a''	n'''	a'''	n''''	a''''	Minimum Charge.
	fr.	km.	fr.	km.	fr.	km.	fr.	km.	fr.	km.	fr.	fr.
1st class	1·00	75	0·10	75	0·08	50	0·06	225	0·04	..	..	1·50
2nd „	1·00	75	0·08	75	0·04	300	0·02	..	..	..	..	1·40
3rd „	1·00	75	0·06	25	0·03	25	0·02	300	0·01	..	..	1·30
4th „	0·50	25	0·06	50	0·04	25	0·02	250	0·01	75	0·02	0·50

The rates do not extend beyond 425 kilomètres (265 miles), as this is the longest distance from one end to the other in Belgium.

The following is an example:—

For a distance of 100 kilomètres, 4th class. Freight = 0·50 +

$25 \times 0 \cdot 06 + 50 \times 0 \cdot 04 + 25 \times 0 \cdot 02 = 4 \cdot 50$ fr., or $0 \cdot 045$ per tonne-kilomètre.

For 200 kilomètres, 4th class. Freight $= 0 \cdot 50 + 25 \times 0 \cdot 06 + 50 \times 0 \cdot 04 + 25 \times 0 \cdot 02 + 100 \times 0 \cdot 01 = 5 \cdot 50$ fr., or $0 \cdot 0275$ per tonne-kilomètre.

For 400 kilomètres, 4th class. Freight $= 0 \cdot 50 + 25 \times 0 \cdot 06 + 50 \times 0 \cdot 04 + 25 \times 0 \cdot 02 + 250 \times 0 \cdot 01 + 50 \times 0 \cdot 02 = 8 \cdot 00$ fr., or $0 \cdot 02$ per tonne-kilomètre.

It is to be remarked that, beyond 350 kilomètres, the rate per tonne-kilomètre remains constant at 0·02 fr., which is the minimum rate of the normal tariff.

For conveying coal the rates in different countries are given below:—

Kilomètres.	Belgium.	Prussia, State Railways.	Alsace and Lorraine.	Franco-Austrian Railways.	Eastern France.
	fr.	fr.	fr.	fr.	fr.
1	0·56	1·00	1·125	1·20	0·48
10	1·10	1·375	1·375	1·31	1·20
20	1·70	1·75	1·75	1·87	2·00
30	2·20	2·125	2·375	2·43	2·80
40	2·60	2·375	2·625	2·99	3·60
50	3·00	2·75	3·00	3·50	4·40
100	4·50	4·25	4·625	5·95	5·40
200	5·50	7·875	8·00	10·19	10·40

In addition to the normal tariff for internal traffic, the basis of which has just been described, there are on the State railways a great number of special low rates, intended to favour the exportation of Belgian products, the importation of certain raw materials, and particular classes of through traffic, e.g. that between the port of Antwerp and the countries bordering on Belgium.

Thus several classes of goods, which rank in the 1st, 2nd, or 3rd class for internal traffic, rank as 2nd, 3rd, or 4th class respectively when exported or imported by sea. Rails, bars, and other kinds of

finished iron, sent from Liége or Charleroi to Antwerp for export, are taken in the 4th class; and there are similar reductions in the classification of other classes of goods.

There are also special tariffs at very low rates for the exportation of coal *viâ* Antwerp or to the north-east of France, for the importation of iron ore to the Belgian furnaces from the Grand Duchy of Luxembourg, for the conveying and exportation of the specular iron-ore of the Meuse basin, &c. The reduction is still further increased for quantities over 100 or 200 tons.

These rates are of great importance for the trade of Belgium; and it may be worth while to give some of the principal rates, as compared with what would result from the application of the normal tariff. The following are examples:—

		Distance. Kilom.	Normal Rate. Fr. *	Special Rates.		
				10-ton Lots. Fr.	100-ton Lots. Fr.	200-ton Lots. Fr.
Ex. I.	Basis of rate	n	F	$n \times 0 \cdot 026$	$n \times 0 \cdot 02$	..
	Liége to Antwerp . . .	120	4·70	3·12	2·40	..
	Charleroi to Antwerp . .	100	4·50	2·60	2·00	..
Ex. II.	Basis of rate	n	F	F - 0·50	F - 1·25	F - 1·50
	Luxembourg Frontier to Charleroi	191	5·41	4·91	4·16	3·91
	Luxembourg Frontier to Liége	167	5·17	4·67	3·92	3·67
Ex. III.	Basis of rate	n	F	F - 0·50	F - 1·25	F - 1·50
	Liége to French Frontier .	166	5·16	4·66	3·91	3·66
	Bracquegnies to French Frontier	215	5·65	5·15	4·40	4·15
	Mons to French Frontier .	240	5·90	5·40	4·65	4·40
Ex. IV.	Basis of rate	n	..	$1 + n \times 0 \cdot 02$	..	..
	Sclaigneaux to Charleroi .	50	..	2·00	..	..

* The normal rate F is calculated according to the formula $F = f + na + n'a' + \ldots$, given above.

The rates in Ex. I. apply to coal, iron ore, stone, and phosphates, for exportation from Belgian ports. The minimum charge is 2·2 fr. per ton for 10-ton lots., 2·0 fr. for 100-ton lots.

The rates in Ex. II. apply to iron ore, imported from Luxembourg to the blast-furnaces of Liége and Hainault.

The rates in Ex. III. apply to coal exported to the east of France, *viâ* Athus or Lamorteau in Luxembourg.

The rate in Ex. IV. applies to iron ore carried from the Meuse to the Belgian furnaces.

Bilbao ore imported *viâ* Antwerp pays between Antwerp and Seraing 4·25 fr. instead of 4·75 fr. per ton.

There are other special rates, given to encourage through traffic, which are sometimes detrimental to Belgian trade; e.g., coke carried from the Ruhr, *viâ* Spa to Luxembourg, enjoys a reduction of 0·70 fr. per ton, compared with Belgian coke over the same distances; and gas-coal on its way from the Ruhr to Paris has an advantage of 1·75 fr. per ton over Belgian coal carried the same distance.

Each department of Government publishes a statistical report every year. From the industrial point of view the most interesting are the reports of the Minister of Public Works, giving a very accurate account of everything relating to the management of the railways, and also to the post-office, telegraphs, bridges and roads, mines, &c.

From the latest of these reports are taken the following figures, which show the importance of the various tariffs described above.

Of the goods carried in 1881 by the State railways, about 43 per cent. were carried at the normal tariff of Class 4; 14 at that of Class 3; 7 at that of Classes 1 and 2; and 36 per cent. at special tariffs. The mean rate per ton was 3·30 francs for a mean distance of 70 kilomètres. Had the normal tariff for the 4th class been applied throughout, the mean rate for the same distance would have been 3·80 francs.

A comparison with other nations will show that as regards cheap transport the State railways of Belgium are in an excellent position. A Report presented two or three years ago to the French Chamber

by M. Waddington, in the name of the Tariff Commissioners, gives the following as the passenger fares for third-class traffic in various countries:—

Norway	3·2 centimes per kilomètre.
Belgium	3·8 „ „
Southern Germany . . .	4·2 „ „
Northern Germany . . .	5·0 „ „
Italy	6·2 „ „
Spain	6·2 „ „
Great Britain	6·2 „ „
France	6·7 „ „
Hungary	6·8 „ „

The average amount received, taking account of reduced fares, is as follows:—

Germany	3·84 centimes per kilomètre.
Belgium	3·88 „ „
France	6·36 „ „
United States	7·30 „ „

According to the same Report and other sources, the average rate per tonne-kilomètre of goods is as follows:

	Year.	Rates per tonne-kilomètre.	Mean distance.
		Centimes.	Kilomètres.
United States	1879–80	4·0	178
Belgium (State Railways)	1881	4·7	70
Alsace and Lorraine . .	1876	5·6	89
France	1878	6·0	132
England	——	7·3	37

Making allowance for the greater average distance on the American lines, it will be seen that Belgium stands in perhaps the best position of any country.

Institution of Mechanical Engineers.

PROCEEDINGS.

NOVEMBER 1883.

The AUTUMN MEETING was held at the Birmingham and Midland Institute, Birmingham, on Thursday, 1st November, 1883, at Four p.m.; PERCY G. B. WESTMACOTT, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and that the following candidates had been found to be duly elected:—

MEMBERS.

HENRIQUE ARENS,	Rio de Janeiro.
EDWARD BICKNELL,	Calcutta.
GEORGE CRAMPTON,	London.
HENRY S. CROPPER,	Nottingham.
FRANCIS WINTHROP DEAN,	Cambridgefort, U.S.
SAMUEL DIXON,	Manchester.
JAMES BROWN EDMISTON,	Liverpool.
HENRY JOHN ELLIOTT,	Birmingham.
LUCIEN GUINOTTE,	Mariemont, Belgium.
NORMAN MACBETH,	Bolton.
REUBEN READER,	Nottingham.
JAMES REID,	Glasgow.
GEORGE JAMES SNELUS,	Workington.
GEORGE PRANGLEY WILSON,	Sheffield.
ROBERT WYLLIE,	Hartlepool.

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GRADUATES.

Hon. Herbert John Cairns, ...	Newcastle-on-Tyne.
Alfred Alphonse Rouff Clinkskill, . .	Glasgow.
Charles Kenrick Gibbons, ...	Newcastle-on-Tyne.
John Kershaw Hill, ...	London.
Harry James Howard, ...	Norwich.
Philip Vincent Lander, ...	London.
Thomas Brown Mackenzie, ...	Glasgow.
William Fawcett Osborn, ...	Sheffield.
Walter Peck, ...	Port Chalmers, N.Z.

The President announced that the President, two Vice-Presidents, and five Members of Council, would go out of office at the ensuing Annual General Meeting, according to the Rules of the Institution; and that the list of those retiring was as follows:—

PRESIDENT.

Percy G. B. Westmacott, ...	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Charles Cochrane, ...	Stourbridge.
Francis W. Webb, ...	Crewe.

MEMBERS OF COUNCIL.

David Greig, ...	Leeds.
Arthur Paget, ...	Loughborough.
Richard Peacock, ...	Manchester.
John Penn, ...	London.
Sir James Ramsden, ...	Barrow-in-Furness.

Of the Retiring Officers the following were nominated by the Council for re-election, as under:—

AS VICE-PRESIDENTS.

Charles Cochrane, ...	Stourbridge.
Francis W. Webb, ...	Crewe.
Richard Peacock, ...	Manchester.

AS MEMBERS OF COUNCIL.

David Greig, ...	Leeds.
Arthur Paget, ...	Loughborough.
Sir James Ramsden, ...	Barrow-in-Furness.

Mr. Penn did not desire to offer himself for re-election.

The following candidates were also nominated by the Council for election at the Annual General Meeting:—

PRESIDENT.

I. Lowthian Bell, F.R.S., Rounton Grange, Northallerton.

Election as Member.	MEMBERS OF COUNCIL.	
1861.	Samuel W. Johnson, ...	Derby.
1869.	William Boyd, ...	Newcastle-on-Tyne.
1879.	Sir James N. Douglass, ...	London.
1879.	Alexander B. W. Kennedy, . .	London.
1879.	William Parker, ...	London.
1882.	William Denny, F.R.S.E., . . .	Dumbarton.

According to the Rules of the Institution, it was now open to any Member to add to the list of candidates.

The President said that the Council had lately had occasion to consider the mode of carrying on the ordinary business of the Institution, and had come to the conclusion that the present arrangement, which had grown up gradually, was not the best that could be adopted with a view to efficiency and economy. They therefore proposed that the Secretary should be solely and entirely responsible to the Council for the carrying on of the business, and should be entrusted with the control of the officers under him. Due notice would be immediately given of an alteration in the bye-laws effecting this change, which would be proposed for adoption at the Annual General Meeting. One result of the new arrangement would be to effect a considerable reduction in the annual expenditure for salaries, leaving a corresponding amount free to be devoted to

the purposes of the Institution. He regretted that the new arrangement necessarily involved the retirement of the present Assistant-Secretary; and the Council proposed to mark their sense of his services, which had now extended over more than twenty-eight years, by presenting him with an *honorarium* of £1000—a course which they felt sure would meet with the approbation of the members. He now gave notice that at the Annual General Meeting in January next he should make the following motion:—"That Bye-Law No. 21 shall hereafter read as follows:—'It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that may be ordered to be read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties; and all members or others calling shall be referred to the Secretary. He shall generally conduct the ordinary business of the Institution, and shall refer to the President in any matters of difficulty or importance, or requiring immediate decision.'"

The President reminded the Meeting that, if any Member had any motion to propose at the Annual General Meeting, in reference to the Bye-Laws, notice must be given of it at the present meeting.

Mr. Arthur Paget gave notice that at the next Annual General Meeting he should propose:—"That words to the following effect shall be added to Bye-Law 20:—'The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.'"

The President announced that the Members were invited by the Council of the Mason Science College to visit the College after the Meeting, for the purpose of inspecting the Lecture Rooms, Museum, Library, &c.; and they were also invited by Mr. Henry Lea to witness in passing the lighting up of the Town Hall by the Crompton-Winfield electric light. They were further invited by Mr. William Bragge to visit the Factory of the English Watch Company, on the following day between the hours of 10 and 1, or 2 and 5.

The following paper was then read and discussed :—

On the Inventions of James Watt, and his Models preserved at Handsworth and South Kensington; by Mr. Edward A. Cowper, Past-President.

On the motion of the President a vote of thanks was unanimously passed to the author, and also to the Science and Art Department, South Kensington, and to Mr. George Tangye, for the photographs presented to the Institution, and for the other facilities given with regard to the models &c. of James Watt.

The following paper was then read and discussed :—

Experiments on Friction; Report of the Research Committee.

On the motion of the President, the further discussion of the paper was adjourned to the next meeting.

The President proposed a cordial vote of thanks to the Council of the Birmingham and Midland Institute for their kindness in throwing open the theatre and rooms to the Members; and to the Council of the Mason Science College, to Mr. William Bragge, and Mr. Henry Lea, for their kind invitations to the Members.

The votes of thanks were carried by acclamation.

The Meeting then terminated.

The Members subsequently witnessed the lighting up of the Town Hall with 600 incandescent lamps, worked by dynamos at a distance of 500 yards, the engine being that of the rolling mill at the works of Messrs. R. W. Winfield and Co.; the orders were given from the Hall by a system of electric signalling. They then visited the Mason Science College, where they were received by the Professors and by the Secretary, and were conducted in parties over the whole building, including the Engineering workshops and lecture-rooms, the Physical and Chemical Laboratories, the Library, the Geological Museum, the various class-rooms, &c. On the following day the Factory of the English Watch Co. was visited, and the various machines and methods of manufacture were fully explained to the Members.

ON THE INVENTIONS OF JAMES WATT, AND HIS MODELS PRESERVED AT HANDSWORTH AND SOUTH KENSINGTON.

By Mr. EDWARD A. COWPER, Past-President.

It is generally known that James Watt left a number of models of various kinds, some at his house, Heathfield Hall, Handsworth, near Birmingham, and some at his works, Soho, near Birmingham; but no general description has appeared of them, and as no explanation or description is appended to them, it is necessary to "*read*" their meaning after careful examination and comparison. This has been attempted by the author, who also suggested that, as many of the Watt models at South Kensington had got the dry rot, and were very badly worm-eaten, drawings and photographs should be taken of them by the Institution, so that a perfect record of them might be obtained before they were entirely destroyed.

The Department of Science and Art at South Kensington very kindly entertained the idea of photographing such models as it was useful to photograph, and have very liberally presented copies to our Institution.

Colonel Stuart Wortley (the Curator of the Patent Office Museum) also kindly allowed particulars to be taken of the parts of Watt's engine and other machines which are in that museum.

Mr. George Tangye, one of our members, has very kindly responded to the author's request to have photographs of the two important machines in the "Watt Room," in Heathfield Hall (now inhabited by Mr. Tangye); and he has had photographs taken of a number of other interesting articles and tools, including Watt's own lathe, work-bench, tools, and old apron, as selected by the author, who had the pleasure of spending parts of two days in inspecting everything in the room carefully, and of sleeping a night in the old house. Mr. Tangye has very liberally presented these photographs to the Institution; and our Council, in the interest of the members,

has had drawings and diagrams made under the author's direction to illustrate the several models and inventions.

It has been found necessary to make a selection from the mass of information so obtained, and it is purposed to engrave and print the greater portion for the use of the members.

In some cases the models are simply duplicates of others, slightly varied in form, but drawings of the most important of them are included in the Figures shown, as per the following list:—

List of Figures.

At the risk of commencing a description of the inventions of James Watt with a thrice-told tale, the author feels bound to take into account, to some extent at all events, the sequence of the inventions of the great man whose works we are endeavouring to decipher. It is sometimes a matter of intense interest to any one who has attempted to improve a machine, to realise the process of thought, through which a successful man of science and practice has arrived at his conclusions, and his triumphs over the elements; as in this case, where literally earth (metals), air, fire, and water have been pressed into the service of man, as much as any "Jack Tar" was ever pressed into His Majesty's service to fulfil a given duty.

The author is obliged to refer to such history as is available, and finds that Watt's patents are probably the most reliable for the dates of his inventions. Many of the models agree with the patent drawings, but there are some models not shown in the patents, and some drawings of which there are no corresponding models.

Now, Watt's first patent of 1769 clearly lays it down (in his own words) that the working cylinder (or "vessel" as he chose to call it) was to "be kept as hot as the steam that enters it, first, by enclosing "it in a case of wood or any other materials that transmit heat "slowly; secondly, by surrounding it with steam or other heated "bodies; and thirdly, by suffering neither water nor any other

"substance colder than the steam to enter or touch it during the "time." The author may perhaps be pardoned for observing here, that it is extraordinary that there should ever have been any doubt in the minds of engineers, since the time of Watt, as to the advantages of steam-jacketing any cylinder that would be otherwise exposed to cooling influences, for the effect on the indicator figure obtained is very marked, as he has before had occasion to observe; indeed engines of the most economical construction cannot be made without steam-jackets. Watt's first patent has no drawings, but in his second patent the steam-jacket is distinctly shown.

Now we must just bear in mind that up to this time the pumping engines that were then at work were *Newcomen's*, and that the practice was to let the steam into the cylinder under the piston, to *allow* it to go up, by means of the weight of the pump-rod &c. at the other end of the beam, and then to *condense the steam in the cylinder*, by allowing *a jet of cold water to play into the cylinder*, thus in time forming a partial vacuum, and causing the piston to come down by the pressure of the atmosphere on the top of the piston; whilst great leakage of *air* past the piston was prevented by the fact that there were several inches of water on it. The cylinder of course was very considerably cooled by the operation. There was no air-pump to such engines, but when the piston had made its down stroke or "gone indoors," there was the condensing water and condensed steam, with what air there might be, in the cylinder: then, instead of all this being taken out by an air-pump, it was *expelled*, through a small valve called a "snifting valve" at the side of the cylinder, close to the bottom, by the fresh steam when it was admitted to the bottom of the cylinder, to let the piston go up again. Such engines could of course only work very slowly, as the cylinder had to be heated up a good deal before the steam would fill it.

The author is sorry to say that the old pumping engine first made by James Watt and used at Soho, for pumping water up into Soho pool, to be used on a water wheel there, has not been preserved; it was ruthlessly thrown away on the scrap heap when dismantled to make room for a larger engine, viz. "Old Bess," as it was called, which the author well remembers seeing as a lad.

His late friend, Mr. Bennett Woodcroft, who had charge of the Patent Office Museum, did all he could to obtain some portions of the first engine, but failed. He was a man who would have done much more for science, had he not been greatly hampered in his work; but it is to be hoped that the Patent Office Museum will in future be the receptacle of many good models of successful inventions, and be in fact a Museum of Reference.

But to return to the history of the inventions we are following. Watt says in a very few but distinct words, that the condenser "ought to be *kept cold*," "by application of water or other cold bodies." He does not say by injection of cold water, neither does he say in words by surface condensation; but it is clear that if the condenser is "*kept cold*" by the application of cold water outside of it, it is in fact a surface condenser, and some books state that he held on to the idea of surface condensation, and persevered in it to a considerable extent, until his condensers got rather unmanageable in size. It will presently be seen how he met this difficulty by an excellent surface condenser, but it is certain that he gradually used more and more injection, as a matter of practice.

It is a curious fact that Watt's most important patent, viz. his first one of 1769, has no drawings at all attached to the specification, but his claims are very clearly stated.

With regard to maintaining a vacuum in the condenser, as every cubic foot of steam takes over a cubic inch or more of air, and as Watt had no "snifting valve" like Newcomen's, he required something to take out such air as entered his condenser, together with the injection water, if any, and the condensed steam; and he says very shortly, "Thirdly, whatever air or other elastic vapour "is not condensed by the cold of the condenser, and may impede the "working of the engine, is to be drawn out of the steam vessels or "condensers by means of pumps wrought by the engines themselves "or otherwise." Thus we have the beautiful invention of the air-pump, to maintain the vacuum in an engine by removing the air.

Fig. 2, Plate 56, is a drawing of perhaps one of the most interesting models of the whole collection, next to those showing the condensation of steam in a separate vessel or condenser, by

means of an injection of cold water; as this model shows the condensation of steam in a separate vessel, or Surface Condenser, composed of a large number of small vertical tubes with the cold water in them, and the steam outside them, which is the best arrangement. It is provided with an air-pump. A section and plan are shown in Figs. 3 and 4, Plate 57.

There are 140 small vertical tubes, and if they are taken to represent tubes about three-quarters of an inch diameter, they would be about 5 feet long. They are, in the model, soldered into the tube plates at top and bottom.

One very remarkable thing about this model, which was suspected by the author before the model was taken to pieces, is that the vertical air-pump has a valve in it, and is worked very much in the same excellent manner that our best horizontal air-pumps in marine engines now work, viz., to move (or "see saw") *the water* from the inlet valve *up to the delivery valve*, thus ensuring the delivery first of all of the air on the top of the water, and then of the water that has to follow the air; so that *no air* may be left in the air-pump. It is to be wished that all modern air-pumps were made as perfect in their action as this one.

This is a remarkable case of a first inventor making an apparatus almost perfect at once, though Watt did not make many of these surface condensers, probably from the expense attending them.

Then follow, in the 1769 patent, clauses for a high-pressure engine to work without a vacuum, when water is scarce, the steam being discharged into the open air after it has done "its office."

It is certainly to be regretted that Watt never followed up the use of *high pressure steam*, as no doubt he would have accomplished much more, and have made more powerful engines, in smaller compass; but he left a great deal of this to Trevithick to accomplish, though he objected strongly to Trevithick, or Bull, using *a separate vessel* for condensation.

In this first patent Watt had other claims for a kind of rotary steam water-wheel; also for a caloric engine, and for using "oils, "wax, resinous bodies, fat of animals, quicksilver, and other metals, "in their fluid state, to make pistons air and steam tight;" but we have no models of such schemes.

Many of his letters prove that he used oil on the piston and pumped it up to use over again, and then he complained that a quantity went away with the condensed steam and was lost. Some piston packings were of pasteboard, soaked in oil and baked, and some of cork; but they did not follow the bad cylinders well, and it would seem to us *now* that it was a pity he did not insist upon having a good cylinder, truly bored out, much earlier.

It is worthy of note that in a letter to a friend he said that he thought he had got his cylinder bored so perfectly that you could not get half-a-crown between the piston and the cylinder anywhere.

Now we must not be altogether surprised at this remark, when we consider with what materials he was in the habit of making his models. He used tin cylinders and soldered joints in many cases, and in one letter he says the cylinder was not very true as it had not been bored, but was hammered; and in another letter he says that he shall in future make his cylinders of copper, as though that was a great improvement upon the material he had been using.

He speaks of his "White-Iron-man," who was so useful, being dead, meaning his "Tin-man"; but it does seem sad that a block tin cylinder that he used, 18 in. diam. and $\frac{1}{4}$ in. thick, should be $\frac{3}{8}$ in. out of truth, and he speaks of trying to improve it by hammering it with a mallet outside, on a piece of wood fitted to the inside. It is curious to think of an optician and mathematician spending time over such imperfect work. His partner Boulton one day writes to Watt, who was away, that he had put in hand a block or boring head, to bore a cast-iron cylinder then in hand, probably one $7\frac{1}{2}$ in. diam.

However, it does not do always to think lightly of others' work, unless we are sure of our ground ourselves. It is possible that there may be a few present, who are not aware that if an ordinary cast-iron cylinder of good size is bored horizontally, it is not fit to be used vertically, or *vice versâ;* as it springs very perceptibly *out of round with its own weight,* independently of the strain due to any chains that may be used to fix it whilst boring. Thus a cylinder, $1\frac{1}{8}$ in. thick, and 4 ft. in diam., will spring out of round with its own weight $\frac{1}{32}$ in., as proved by repeated experiments. This was tried by the author in 1845, and again lately; and it is evident that

different parts will spring differently, according to their stiffness and size of flanges &c.

Fig. 1, Plate 55, taken from 'Farey's Treatise on the Steam Engine,' is in fact one of Watt's earliest pumping engines, single-acting, without a fly-wheel or any rotary motion, but with a steam-jacket to keep the cylinder warm, and a separate condenser to condense the steam without cooling the cylinder; with an injection pipe and an air-pump, but no parallel motion, there being segments on the ends of the beam, commonly called "Horse-heads" in those days.

Now, an open-topped cylinder is shown in his 1781 patent, and a stuffing box to the cylinder cover in his 1782 patent; but it appears from Watt's notes to Robison's articles on Steam and Steam engines, written for the Encyclopædia Britannica, that Watt, even by 1774, had closed the cylinder at top, and put a stuffing-box for the piston-rod to pass through. The useful effect of so doing in a single-acting pumping engine is to exclude the atmospheric air from the cylinder, and let the *steam act* on the top of the piston when there is a vacuum below the piston, and it is making its stroke "in-doors;" then, when the piston is about to rise or go "out-doors," the steam on the top of the piston is allowed to pass to the bottom through a valve, called the "Equilibrium Valve," and, when the piston has risen, this steam is let out into the condenser, and fresh steam is allowed to flow on to the top of the piston. In this way the cylinder never has any air admitted inside it.

This was a grand improvement upon Newcomen's engine; for less steam was required to do a given duty in pumping, and the engine could be worked much quicker, as no time was lost in heating up the cylinder and cooling it down again to obtain a vacuum.

The time required for a stroke was simply the time the steam took to flow through the passages, and the water to move through the pump.

A noticeable feature in most of the models is the absence of anything like a large condenser or separate "vessel" for condensation, as in most cases the injection pipe is shown throwing its water up the eduction pipe, so as to meet the steam coming from the cylinder to the air-pump, thus making the pipe itself into the condenser.

In Watt's patent of 1781, a number of very ingenious contrivances for converting the reciprocating motion of the piston into a continuous rotatory motion are shown and described, though it must be at once freely admitted that none of them are so good as a common crank.

It appears that a man of the name of J. Pickard in 1780 took out a patent simply for the one object of converting reciprocating to rotary motion in a steam engine by means of a crank, and it has been said (but the author cannot say with what truth), that he was a workman of Watt's, who learnt that Watt had invented such a mode, and then went himself and patented it; it has further been said that Watt would not attempt to make any terms with the man, and would not run the risk of a lawsuit. However, in the specification to the patent of 1781, Watt shows both a single crank, and two cranks at right angles, having connecting-rods to them, to enable the two engines to work on one crank-shaft. These cranks are pins in discs, and are not called cranks in the specification, but "*points of attachment of the connecting rods*"; this would seem to be a distinction without a difference. See Figs. 5 and 5*a*, Plate 58.

The model now exhibited is a model of an engine made according to Watt's patent of 1781; it is single-acting, and has an open-topped cylinder with air-pump, condenser, and heavy balance weight on the connecting rod, to give the impulse in one direction, whilst the piston at the other end of the beam gives the impulse in the other direction by means of the vacuum then produced in the cylinder; thus obtaining rotative motion. This model has been kindly sent here by Mr. E. B. Marten for exhibition, and is shown in Figs. 9 and 10, Plate 59.

The next best plan is the well known "Sun and Planet" motion, Fig. 7, Plate 58, in which a spur wheel, *rigidly fixed* on the end of the connecting-rod, gears into a spur wheel of equal diameter on the engine shaft, and is kept in gear with it by a pin or roller behind the centre of the pinion, running in a circular chase or groove provided for it. Another plan of keeping the wheels in gear (Figs. 11 and 12, Plate 60), which has often been adopted, is that of a *link*, having one end turning freely on the engine-shaft, whilst

the other end confines the centre pin of the spur wheel fixed on the connecting-rod. The author has had to make some alterations in one of these engines within a very few years; it is only a "stand-by" engine, but is occasionally worked, and goes very well when the mortice pinion has been recently re-geared. Of course the engine-shaft goes double the speed of an engine with a crank. Figs. 11 and 12 represent an actual engine of this type, now preserved at the Patent Office Museum.

Another form of "Sun and Planet" motion (Fig. 13, Plate 61) is one in which the "Planet" spur-wheel is an internally-geared wheel, and is kept in gear by means of a roller at the lower end of the connecting-rod, running around an oval-shaped cam or guide-block.

Fig. 8, Plate 58, shows a "Spur Planet" on the connecting-rod, and internal gear on the shaft.

Then there are two forms of eccentrics on shafts, one a solid one, with an eccentric-rod embracing it, but provided with rollers to bear against the eccentric to reduce friction (Fig. 6, Plate 58), and the other a hollow eccentric, with the end of the eccentric-rod fitting inside it, but provided with a roller to reduce friction.

Another scheme in this specification for producing rotatory motion is a very peculiar one, and consists of a very large and heavy "Crown Cam" (Figs. 17 and 18, Plate 63) on a vertical axis, and having two rollers on a rocking frame to act against its curved face; this rocking frame being moved up and down by the beam of an engine.

Another model, of which Figs. 15 and 16, Plate 62, are drawings, consists of a long rack on the end of the connecting-rod, as much like a ladder as possible, taking into the teeth of a spur-wheel on the engine shaft; the rod being guided by two fixed pins or rollers, which keep it close in gear with the spur-wheel throughout the greater part of its stroke, up or down, and by two projecting pins on the rod to keep it in gear when turning the centres, one pin working in a semicircular guide when turning the top centre, and the other pin working in another semicircular guide when turning the bottom centre.

Fig. 14, Plate 61, shows another arrangement of rack and pinion,

or "Ladder Motion," as it may be called, in which the bottom end of the ladder carries a roller, and this roller works in a large opening of peculiar form in a guide-plate round the shaft and pinion which the "Ladder" drives, as it is moved up and down by the engine. The guide-plate thus keeps the "Ladder" always in gear with the pinion on the shaft.

One strong peculiarity throughout this 1781 specification is that all the engines are *single-acting*, so that in every case a *heavy-balance weight is required*, to make the piston of the engine make the "out-door" or up-stroke. The rotative engine thus arranged is twelve years after the pumping engine.

Referring now to the 1782 *patent* (thirteen years after the first patent), a further *great improvement* is found in an engine that Watt describes as "The new improved engine, the piston of which is "pressed forcibly *both upwards* and *downwards* by the power of steam," that is to say, the engine is no longer single-acting but *double-acting*, as in Figs. 30 and 31, Plate 72. Here we find the chain, which hitherto commonly connected the piston-rod to the beam in a pumping engine, entirely put aside, and a *parallel motion* or other connection introduced to enable the piston to *push* as well as to *pull*, thus superseding the heavy balance-weight. The parallel motion, in several forms, including those now used, is distinctly the invention of James Watt.

It would appear from the specification of this 1782 patent that the closing of the top of the cylinder, and the addition of the stuffing-box, was new at this date; but Watt's notes on Robison's work, mentioned above, show that he was using it about 1774, and if so, some of the early single-acting pumping engines, and the rotative engines with heavy balance-weights, probably had covers and stuffing-boxes.

The author well remembers several old rotative engines in the Black Country (one near West Bromwich, and one near Netherton), with a heavy weight in the form of a large slab of cast iron on the connecting-rod, and an open-topped cylinder, in which one could *see* the piston rising and falling; such engines were worked with steam of several pounds pressure above the atmosphere.

It should be noticed that what is now commonly known as the single-acting pumping engine has the stuffing-box and cover, and the equilibrium valve.

In the patent of 1782 Watt states that there are various arrangements that may be made of the several engines, but that he has given only those that appeared the best, and this no doubt is the case, and is what a patentee is bound to do. The author has found a model at South Kensington, which he takes to show a transition state, or form of engine that may probably represent an attempt to produce a double-acting engine by two single-acting cylinders, connected together by a chain over a pulley as follows.

Fig. 27, Plate 69, shows two single-acting vertical *air-pumps* placed at some little distance apart, and with passages below leading to them; and there is an unique arrangement of two single-acting vertical *cylinders*, having their upper ends connected by a passage without valves, but the pistons having self-acting valves in them, opening upwards, so that *any steam* below *either piston* could pass to the *upper sides* of *both* pistons. A chain connects the top ends of the piston-rods together, and it passes over a pulley or drum to which it is attached, so that the drum will *reciprocate*, if the pistons work up and down in the cylinders.

To the drum is attached a long crank-pin, which could take hold of a pump-rod, or a connecting-rod.

There are conical valves to let steam into and out of the bottoms of the cylinders, and in each passage leading downwards from the eduction valve there is a small pipe, terminating in a jet pointing upwards, no doubt for the *injection water*. Now, although when the models were first examined there was not the slightest indication that these pumps belonged to the cylinders, it appeared probable to the author that they had some relation to each other; and on further examination, two dowel-pins were found on one model, and two holes were found on the other model, into which the dowel-pins fitted, thus at once proving that the supposition that they belonged to each other was correct.

Thus we have a model of a double-acting arrangement for pumping or other reciprocating motion, such as a connecting-rod or

crank, with the pressure of the steam *always* on the tops of *both* pistons, and a vacuum formed alternately under one or other of the pistons, by injection of cold water into the eduction pipes; and with air-pumps to keep up the vacuum, and discharge the air, and the water of condensation, and the condensed steam. This is an arrangement that has not before been noticed, and of which, it appears, there is no description extant; it is a good example of the ingenuity and inventive genius of James Watt.

Another *grand invention* in this 1782 patent is the use of steam *expansively;* and so thoroughly did Watt understand this action, that he has drawn a good indicator figure of what would take place in the cylinder of an engine, if the steam were cut off at one quarter of the stroke. See Fig. 25, Plate 68.

This figure, the author finds, is identical with Marriotte's Law, and not far from the true expansion curve that the author constructed from Pambour's table of the bulk of steam in proportion to the water that produced it; that is, so far as the figure goes, *i.e.* to an expansion of steam at atmospheric pressure to four times its volume. (The author's diagram, Fig. 26, Plate 68, goes to 44 times the volume, with 120 lbs. steam.)

At this point, it may be well to leave the consideration of the specification for a moment, to examine the drawing, Fig. 19, Plate 64, of a model which it is believed is at the root of the invention of the "*Indicator.*" This consists of a simple, small cylinder about 2 in. diam. and 3 in. stroke, open at top and closed at bottom, and with a cock and pipe to it; the piston-rod is connected by a light chain to a rocking-beam above, and a chain fastened to the other end of the beam is attached to the upper end of a good spiral spring, fastened at its lower end. There is a long light finger on the centre of the beam moving in front of a large segment. Now, if the pipe below was connected to an engine cylinder, and the cock opened, the degree of vacuum in the cylinder would at once be *indicated.* It only remains now to attach a pencil to the top of the piston-rod of this indicator, and move a sheet of paper on a board in front of it, to and fro, as the main piston of the engine moved, and we have "Watt's Indicator" as used by himself and all his people

for very many years, in fact up to the author's time, when he saw the instrument in Mr. William Bennett's possession in Manchester. Mr. Bennett then showed the author's late father how to take indicator figures, of which some are shown in Figs. 23 and 24, Plate 67, taken by Professor Cowper in 1840.

Mr. W. Bennett was originally at Soho, and on going to Manchester and joining Mr. Wren, he became Messrs. Boulton & Watt's agent there, for indicating their engines and taking orders for the same.

Our member, Mr. Henry Wren, has very kindly made the author a present of one of these indicators, shown in Plate 65, Figs. 20 and 21, and it is now before you; you will see that it is just like the engravings of Watt's indicator in the Encyclopædias.

Watt goes on in his specification to say that when the steam is cut off at one quarter of the stroke, there must be an equalising arrangement, to enable the piston to complete its stroke when pumping; and several plans are put forth. In one, Fig. 22, Plate 66, there is a small fly-wheel with a pinion mounted up above the cylinder, the pinion taking into a toothed segment on the end of the beam (in place of the old "Horse-head"). The piston-rod has a rack attached to it, also taking into the toothed segment, so that at every stroke of the engine, either up or down, the fly-wheel must start from a state of rest and revolve rapidly and then stop, and in so doing would of necessity take a good deal of power to overcome its inertia, and would give it out again (less the double friction) towards the end of the stroke. Another plan is, to mount a weight high up on the top of the beam of an engine, so that it should be somewhat lifted, in starting from either end of the stroke, and fall somewhat after passing the centre. Another plan is that of a loose weight, to roll along the top of the beam and do the same thing. Again, one plan is to have two large, short-stroked, open-headed pumps, one attached to the beam on either side of its centre, so that one bucket rises while the other falls; and there being a trough between the heads of the pumps, the water is intended to flow from the one to the other, thus giving the engine more to do at the commencement of the stroke, and gaining a little

towards the end of the stroke, by the weight of so much of the water as has flowed over in the time.

There are also several arrangements of levers, to give a variation in the leverage during the stroke, so that the piston should have more to do at the commencement of the stroke, and less to do at the end, when the steam was gradually losing its pressure from expansion.

Thus, in 1782 Watt had made a thoroughly good rotative, or mill engine, and an economical one also, though it does not appear that he actually used any considerable pressure of steam at any time. This engine is shown in Figs. 30 and 31, Plate 72, taken from a model in the South Kensington Museum.

One form of engine he describes, and which he calls a compound engine, consists of using two cylinders of the same size, and then, having used full steam in one cylinder, he lets that piston stand still whilst part of the steam expands into the second cylinder, and finally the steam from both is condensed.

In the patent of 1782 is described the plan of allowing the piston-rod of an engine to pass out through a stuffing box in the bottom, the beam being placed below, like what is now known as a "Bull Engine," (Figs. 28 and 29, Plates 70 and 71.) It is believed the name arose from an engineer of the name of Bull, who put some up in Cornwall, and whose son went into partnership with Trevithick, at the time that James Watt was complaining of their infringing his first patent for the condensation of steam.

It is a remarkable fact that the model from which this diagram was taken is almost exactly the same as the engraving at page 59 of the 'Life of Trevithick,' the injection jet being in the eduction pipe, as shown in some of Watt's drawings.

Watt, in a patent of 1784, describes an ingenious method of obtaining rotary motion in opposite directions, by two connecting rods from a crosshead at one end of the beam of an engine (Figs. 32 and 33, Plate 73). Inasmuch as one shaft is placed somewhat lower than the other, that rod is jointed to a lower part of the beam, so that both may turn the centres at the same instant. The lower shaft drives the bottom roll of a rolling mill, and the higher one drives the

top roll. This was probably intended for rolling metals for coining. The gearing by spur-wheels carries the power to another mill for slitting.

In the same patent the idea of a steam carriage for common roads is put forth, to be worked by steam above the pressure of the atmosphere, which is to be allowed to escape into the atmosphere when it has done its work; a fore-carriage and steering apparatus is named, and a light and portable boiler with the fire inside the boiler in an iron tube, whilst the body of the boiler *might* be made of wood for lightness, and be strongly hooped to retain the steam.

The author may mention the fact that some internally-fired boilers for practical work have had their shells made of wood; as his late uncle, about sixty years ago, assisted in the construction of one for a dredger in London, in which thick planks, well tongued together, and jointed with white lead, formed the sides and the top and bottom, there being a mass of clay placed on the top to help it to withstand the pressure of the steam. The pressure was very low, and the engine of the dredger was a condensing engine.

Watt went so far into detail as to give the diameter and stroke of the cylinders for a small steam carriage, to take two persons, viz. 7 in. cylinder, 12 in. stroke.

Watt says, "The elastic force of the steam in the boiler must "occasionally be equal to the supporting a pillar of mercury 30 in. high."

In spite of this, however, it is said that the firm of Boulton and Watt endeavoured, about 1804, to obtain an Act of Parliament to prevent more high-pressure engines on Trevithick's plan being made, on the ground that, "the lives of the public were endangered."

It may be only right here to mention that the present eminent firm of James Watt & Co. have discarded such limitation of pressure, and have for a long time made highly economical engines of all kinds, high-pressure, expansive, and condensing.

It is worthy of note that one Cugnot, a native of Lorraine in France, made in 1769 a steam carriage for common roads; it had three wheels, and two steam cylinders single-acting, and a short beam between them, and they worked on to the axle with ratchet

wheels. The carriage went at $2\frac{1}{2}$ miles an hour for a short time. The author saw this old engine in an old church connected with the "Conservatoire des Arts et Metiers" in Paris.*

One Francis Moore, a draper in London, invented a steam carriage in 1769, as mentioned in the letters of Dr. Small and Mr. Watt.

There is one Model, Fig. 38, Plate 75, which shows two hammers, worked by one engine, the one lifted by a cam from the "belly" like an ordinary forge hammer, except that the shaft is at right angles, whilst the other hammer is lifted by depressing the tail like a tilt-hammer by another cam.

This model was only just saved from destruction, as the shafts of both hammers were so worm-eaten that one had fallen to pieces and the other was nearly as bad; however, the authorities have kindly put a new wooden shaft, prepared by the author, precisely like the old, to the hammer-head that had fallen off, so that now it can be understood what the model is really intended to show.

The patent of 1785 is for a wagon boiler and the setting of same; this is an early form of such a boiler, and the sides are shown vertical. In 1833 the author (through the kindness of Mr. W. Bennett) was allowed, as a lad, to copy the working drawings of one very like it, except that the sides were curved to give extra strength, while stays were introduced inside, to tie the sides together. Of course it is evident that flat sides of boiler plate were exceedingly weak, but Watt generally worked with very low pressure, only a very few pounds above the atmosphere: when 7 lbs. steam pressure was carried, it was considered about as far as it was proper to go, and even then the "open feed head" had to be carried up some 18 or 20 feet, to prevent frequent "boiling over."

In fact, in practice Watt trusted to the vacuum to give him his power, and the iron plate of the boiler was rather to prevent the admixture of atmospheric air with the steam than to give him any high pressure.

So great in fact was the objection at that time to high pressure, that when offered an order for locomotives for an early railway, the firm would not look at it.

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* This is fully described in Proceedings 1853, p. 33.

There are two very striking inventions of steam engines altogether different from the steam engines previously spoken of, and acting in a different manner; one is a rotary engine, Fig. 37, Plate 74, and the other a semi-rotary engine, Figs. 34, 35, and 36, Plate 74. In the rotary engine there is a piston, fixed as an arm, in a radial line to the shaft to be turned, and the cylinder of the engine fits the piston in its revolution; there being at one point a flap-valve, hinged to the inside of the cylinder, whilst its other end rests on the shaft, so as to form a cylinder bottom, or *point d'appui*, for the steam to act against when acting also on the piston. This flap-valve is at a slight angle to a radial line, so that when the piston comes round, it can heave it up so as to get past. This is about the simplest form of rotary engine that can be conceived, and has probably been re-invented fifty times since 1782.

The semi-rotary engine, Fig. 34, has likewise a piston fixed in a radial line to the shaft to be turned, and the cylinder fits the piston as it moves backwards and forwards through a considerable arc of the circle; fixed inside the cylinder at one part is a fixed stop or cylinder bottom, for the steam to act against *either way*, as it acts against the piston in either one direction or the other. It was intended to let the reciprocating shaft act with a spur wheel on two racks attached to the pump rods.

There is an unfinished model of this engine in the "Watt Room" at Heathfield Hall, which the author has examined; no doubt this was partly made by Watt's own hands. In a letter of Watt's, dated 27th September, 1782, he speaks of this model having been made, so far, in 1765 or 1766.

It remains now to give some description of the more important articles found in the "Watt Room" at Heathfield Hall, the residence of our Member, Mr. George Tangye, who, as before mentioned, has kindly photographed many articles for the Institution.

The room is about 20 ft. by 16 ft. 6 in. in size (see Plan, Fig. 49, Plate 81, and interior view, Fig. 57, Plate 86), and really is a good attic, and nothing more, with one low long window only 5 ft. 4 in. from the top to the floor, so that it was a bad light for any machine

a few feet from the window; and it is a wonder that Watt did not devote a better room to his purposes.

There are numerous shelves with drugs and parcels on them, and nests of small drawers with tools in them, some of them very excellent tools; and his small lathe and bench stand at the window, with his tools about, and his old leather apron on the vice, and his centre-punch tied with a piece of cat-gut to the vice, to save him the trouble of looking for it, or picking it up. There are now a number of busts on a bench in the room, and some marble and alabaster for working on. At the fire-place there is his old frying-pan and his Dutch oven or "hastener," and outside the door, on the landing, a little shelf, on which it is presumed his meals were placed.

Besides these things there are two large machines for sculpturing marble, alabaster, or wood, and a few smaller half-finished models, such as the semi-rotary engine just named, and a "counter," Fig. 41, Plate 78, for counting and recording the number of strokes that an engine makes. This is constructed on the intermittent principle; that is to say, the first wheel has 10 teeth, and when it has received 9 impulses from 9 strokes having been made, the 10th stroke not only turns the first wheel one tenth, but this wheel, owing to its having a raised tooth at that particular place, turns the next wheel one tenth also, thus scoring one tooth on the 2nd wheel, and so representing 10 strokes; and so on throughout the series, so that when 999 strokes have taken place, the next stroke in fact moves all three wheels, which then show 000, and the fourth wheel goes one tooth suddenly, and thus shows 1000.

There is a modification of this counter, Figs. 43 to 46, Plate 79, at the South Kensington Museum, in which there are seven wheels and pinions all geared together, the wheels having 100 teeth and the pinions 10 teeth, so that all the wheels are always moving when one moves. This is a very safe instrument, but is not quite so clear to read. It is believed that these are the first "counters" that were ever made, at all events to go to millions as these do.

An exceedingly simple, but handy plan, of blocking up anything to a given height is shown in Fig. 50, Plate 81, being in fact only a pair of "folding wedges," but with a number of notches in the

lower W edge, into which a pin, fixed in the upper W edge, can drop, and so keep them from sliding when at almost any exact height.

In this room the author found a large number of little slips of copying paper, with various receipts for making copying ink, and in one corner of the room a small "Letter-copying Screw-Press," that would take in such slips conveniently, Fig. 51, Plate 81; the screw was only of wood, but powerful enough for the light work it had to do. This is shown in Watt's 1780 patent, together with his "Letter-copying Roller-Press," Fig. 47, Plate 80, of which there is also an example at South Kensington, together with his old desk, in which he had a pair of small rollers fitted for the same purpose. These two last belong to Mrs. Bennett Woodcroft. The drugs on the shelves were many of them for the purpose of making the "Copying-ink powders" that Watt used to sell at ninepence a packet, and of which there are some dozens now at Heathfield Hall. It is believed that he sold these on his own account.

The next machine to be noticed is a very remarkable one, when we consider the date at which it was made, viz. 1809. It is a machine for sculpturing or copying a bust or bas-relief of the same size as the original; it is shown in Fig. 52, Plate 82, which is copied from a good photograph kindly taken by Mr. George Tangye at some considerable trouble. Watt called this machine an "Eidograph," and there are some drawings of parts of the machine in the room.

The machine consists, firstly, of an ordinary lathe, with treadle and fly-wheel, to supply the motive power, and secondly of two tall uprights about seven feet high, carrying at the top a slide on a strong horizontal bar; the slide being capable of motion horizontally, either at a slow or quick speed. Then, hinged to this slide, is a light square frame of metal, and, at the outer edge of this, another light square frame of metal is hinged, so that the lower edge of such frame is capable of motion up and down, or in and out, like an elbow joint, and horizontally when the top slide is moved.

The weight of these frames is balanced by levers and balance-weights and chains above, and the lower edge of the second frame is furnished with a "feeler" or "guide" to traverse over the original model, and a "drill" driven at a high speed by a light cord to cut

the work or copy; so that by handling the feeler carefully and tracing over the original in all directions, a piece of marble or alabaster or wood, placed in the machine alongside of the original, is cut to a perfect copy by the machine without fear of any mistake, and without any special skill on the part of the operator. The slow motion to the slide above, carrying the frames and "feeler" and "drill," is worked by a convenient handle and tangent-screw when cutting, and the quick motion can be thrown into gear with the lathe wheel to run back. The *quick* motion has a *coarse* traversing screw, having a nut in halves, that can be closed or opened; and the *slow* motion has a *fine threaded* screw with a similar nut, so that it also can be thrown into gear or released. A handkerchief is wrapped around a part of one frame, in such a position that one could put one's head against it, to push it up off the work at pleasure, besides moving it by hand.

There is a noticeable feature in the frames above mentioned, and that is, that in order to prevent their springing or going "winding," they are practically formed into "solids" by the erection of the outlines of a pyramid on each. Fig. 42, Plate 78, shows a similar frame, apparently an experimental one, found hanging on the wall: this is even better theoretically than the one in the machine itself. The plan gives extreme stiffness, at the expense of very little weight. The author considers it an extremely ingenious method of preventing a framing from going "winding," and one that he has not seen before.

After searching the room over, two specimens of work were found, one a finished original bas-relief, and the other the unfinished copy of it, Fig. 54, Plate 84. Both the original and the copy can be mounted in their places in the machine, and be turned precisely together by a pinion gearing into the two wheels on the mandrils of the carriages on which the articles are placed, so that "undercutting" could be properly accomplished, as well as straight cutting into the work by the "drills."

The drills, circular-cutters, and other cutting tools (of which some are shown in Fig. 55, Plate 85) are excellent, some being formed for roughing out apparently, and made to cut in steps, *i.e.* to take

several light cuts, and some in the form of globes with the whole surface formed into numerous cutting edges, so that it was a cutting globe, so to speak, and could go anywhere, as it would cut in any direction.

Fig. 53, Plate 83, shows the sculpturing machine for making a copy of a reduced size. After searching the room thoroughly, two "masks" or half faces, Fig. 48, Plate 80, were found, the one eight times the size of the other, and the smaller one undoubtedly executed in this machine. Some drawings found of parts of this machine give 1811 as the date. Watt called it a "Diminishing machine."

The machine consists, firstly of a lathe bed, with fly-wheel and treadle for obtaining the motive power for driving the drill; secondly of a stout hollow tube forming a long lever, fulcrumed at one end on a "universal joint," so that the other end can be moved in any direction about the centre. This lever carries a "feeler" or blunt point near its outer end, and a "drill" near the fulcrum, so that whatever motion the "feeler" has, the "drill" has (say) one-eighth part as much. Thus, if a bust or mask (in this case a plaster cast) is placed on the slide provided for it under the "feeler," and such "feeler" is carefully traced all over it, the "drill" will cut a piece of material placed under it, on the slide provided for it, to the same form, except that it will be one-eighth the size of the original. The lever is balanced.

The slides above named slide on the bed of the lathe, and are moved by a "pentagraph," or arrangement of levers, to give one-eighth as much motion to the work to be cut as to the original, so that every dimension shall be in proportion. A further motion is provided for turning round the original and the copy, as is sometimes necessary when undercutting a "bas-relief," and of course when copying the round figure.

One example, and one only, was found of the round figure, viz. an unfinished head and bust in wood, Fig. 56, Plate 85, so small that no doubt it was done in this machine from a larger original.*

* The Secretary has since been informed by Mr. Samuel Timmins that several beautifully finished miniature busts by James Watt exist elsewhere.

It would appear that the machines just described were used by James Watt, probably as a mere amusement for his leisure, during the latter days of his life; for they do not appear to have been patented by him, or in any way brought before the public. It is to be hoped that in the pursuit of this hobby he found agreeable relaxation and relief after the laborious life which he had long led.

In conclusion, the author would draw attention to the general effects produced by the inventions of James Watt.

Firstly, In 1769 there were many Newcomen engines at work pumping (in fact Watt's attention was first drawn to steam engines by having to repair a model of a Newcomen engine), and the effect of his invention was, to work *pumping engines* more economically and quickly.

Secondly, In 1781 he produced rotative power for driving factories, obtaining it, in a manner, by having a heavy balance-weight to act one way whilst the steam acted the other way; however the *obtaining rotative motion* by steam was an *enormous advantage*, far greater in its effect, in the author's opinion, than the improvement in the *pumping engine*.

Thirdly, The crowning invention of 1782 made the steam engine the one useful motive power, by making it *double-acting*, and fit to drive cotton mills, flour mills, and all other machinery requiring regular rotative motion.

The general effect of this invention on the manufactures of the world, and first, of course, on those of this country, is so widespread that it cannot be estimated; it has cheapened production to a marvellous extent, has in very many instances been the means of bringing new manufactures into existence, and has immensely increased the intercourse between nations, by developing from fire and water as many *tame giants* as we require to do our work.

Abstract of Discussion on Inventions of Watt.

Mr. Cowper said there was one model at South Kensington, shown in Figs. 39 and 40, Plates 76 and 77, which he had not described in his paper, for the simple reason that he had not yet been able to see the inside, so as to ascertain its exact construction.*

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* Since the reading and discussion of this paper, Mr. Cowper has had the advantage of inspecting the interior of the model. A section is shown in Fig. 40, Plate 77. It consists of an external cylinder AA, closed at the bottom and at the top, and an internal cylinder CC, which is closed at the top and open at the bottom. Therefore any steam passing in at the opening B would pass into the cylinder below the piston (as shown at D), and also into the space between the two cylinders. Hence that inside cylinder is a *steam-jacketed* cylinder; and this is the very first thing Watt mentions in his first patent, viz., that the cylinder is *to be kept as hot as the steam used in it.* There is no doubt this piston leaked as much steam through as all the other pistons that Watt experimented with, and complained of from first to last as being leaky. In one instance Watt suspected that the pistons leaked so much that it would take just as much steam from the boiler whether the engine was working or not; he stopped the engine, and tried the experiment, and found that it was so. It may certainly be assumed that this piston did leak like all the other pistons, as both the internal and external cylinders are only of tin-plate, very roughly soldered up, and showing the lap joints. The pipe E, connected to the separate condenser F, is connected to the external cylinder only; and an air-pump H is arranged to draw from the separate condenser.

Assuming that the steam was admitted at the hole B when the piston was half way up in the cylinder, it would fill the steam-jacket and the cylinder below the piston, driving the air out through the condenser, and through a snifting valve at G, the condenser being full of water at the time, owing to the piston of the air-pump being at the bottom of its stroke. If now the steam were shut off, and a quick upward stroke were made with the air-pump piston, the level of the water in the condenser would be brought right down to the bottom of the condenser, and the steam in the jacket and in the cylinder below the working piston would be condensed suddenly (or "in a crack," as Watt said), and the working piston would go down with the full force of the steam or air above it and the vacuum below it, and thus make the stroke. On again forcing the air-pump piston down, the water in the condenser would be raised to the level of the pipe E as before.

He would also call attention to a beautiful engraving kindly lent by the authorities of the Reference Library, Birmingham; it had formerly belonged to Mr. Samuel Timmins, and had been presented by him to that library. There were only two copies extant,—the one now exhibited, and another in the Salt Library, Stafford. This engraving (reproduced in Fig. 58, Plate 87) was distinctly a Newcomen engine with an open-topped cylinder. There was a beam with segments at the ends, and there was a boiler below; and there was a plug-frame with a self-acting tappet arrangement for moving the valves. That was evident, because the stoker was at work stoking the boilers, instead of attending to the hand-levers, and therefore the engine must be intended to work of itself. There was also a long description, comprising fifty-four articles, even descending to the seat where the men were to rest "when they are weary." That engine was put up very near Wolverhampton in 1712, and he believed it was the first large engine that Newcomen put up. He would call attention to the date and to the fact that many were put up subsequently; so that pumping engines according to the Newcomen plan were pretty common in the country many years before the time of Watt, in 1769. The two first inventions of Watt in that year, beautiful as they were, simply for the time caused those engines to be worked quicker and more economically. There was no idea of rotary motion, but for eleven years, from 1769 to 1780, they were simply improved pumping engines. When in 1781 Watt produced the rotative engine, it was

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It is true that, if such were the working arrangements followed by Watt, there would appear to be no provision for a supply of cold water for condensing purposes; but in a very rough model like this it was probably considered that, if a few strokes could be obtained, showing a reasonable exertion of force, it was all that could be expected.

There has evidently been at one time another hole J near the top of the external cylinder, with a short pipe leading through to the internal cylinder; and if the separate condenser and air-pump had been connected here, the result would have been far better, as then the steam in the internal cylinder *only* would have had to be condensed at each stroke, and a full-length stroke could have been obtained. This model it is presumed was a very early one, and may have been Watt's first attempt with a steam-jacketed cylinder kept hot and a separate condenser kept cold.

as in the model, Figs. 9 and 10, Plate 59, with an open-topped cylinder, single-acting, the return stroke being made by means of the heavy balance-weight. Immediately after that, in 1782, he hit upon the plan of closing the cylinder at top, and making a complete rotative engine, as in Figs. 30 and 31, Plate 72, with steam admitted to each end of the cylinder, or double-acting, and also with a crank, fly-wheel, and air-pump; pretty much as it still existed in the ordinary form of condensing engines. In those times Watt always worked with very low pressure, and it was a very common thing with the old boilers (he had seen it himself again and again) to see their flat ends bellowsing or panting at every stroke of the engine. A friend of his had seen an engine working in the Black Country with the man-hole lid off, just sufficient steam being produced to come curling out at the man-hole door. His friend told the fireman that the man-hole lid was off; but the man replied that the engine worked just as well whether it was off or on, which was a fact, because it was working simply by the condensation of the steam admitted at atmospheric pressure into the cylinder. There was no doubt Boulton and Watt trusted to that mode of working for very many years. In the engines they put up in Manchester it was considered within his own memory a very good thing to go up to 4 lbs. or 5 lbs. The indicator diagrams, Figs. 23 and 24, Plate 67, were considered to be excellent, because they showed 14 lbs. per sq. in. average pressure instead of 7 lbs. per sq. in., on which the power of the engine was calculated. It was a very great pity that Watt did not carry out what he had patented, namely working engines with steam at a considerable pressure. Some eighteen years after the date of this patent, Trevithick was working with 120 lbs. in the boiler; he certainly did run some little risk, because he used cast-iron boilers, cast in one piece, about 5 ft. long and 3 ft. 6 in. diameter; and it was in consequence of this that Boulton and Watt went to Parliament for an Act to try to stop this headlong course.

There were a few of Watt's old engines at work at the present day. He had one under his superintendence in London, as mentioned in the paper, and at the same place he had pulled down probably the last hay-stack boiler in London. It was an old copper boiler,

the rivets were $4\frac{1}{2}$ in. apart, and the rivet heads were about as big as saucers—a most curious thing. He had taken out two other old boilers in London—wagon boilers, working at very low pressure; they were plugged with wood in several places, and he believed these were about the last left in London of those old-fashioned boilers.

Mr. SAMUEL TIMMINS felt bound as a resident in Birmingham to thank Mr. Cowper very heartily, and also the Institution of Mechanical Engineers, for the skill and care with which they had endeavoured to preserve some memorials of the most interesting room in the whole area of Europe. He had himself spent, with a dear friend now no more—the late Mr. W. C. Aitken,—many pleasant hours in the room which had been so admirably described in Mr. Cowper's paper. He had been told by Mr. W. P. Marshall that several members of the Council had had the same pleasure that day; and he was quite sure they would agree with him that a more interesting or inspiring visit could not well be made than thus going as it were into the very presence of a genius long since passed away. The Mechanical Engineers of England were the lineal descendants of James Watt, the heirs-at-law, so to speak, of his inventions. He was therefore especially pleased to find that they had found time, amid their many avocations, not only to look to the present and the future, but also to take a deep interest in the past.

Perhaps he might be allowed to express a hope that the body of engineers present would unite with those of Birmingham in the desire that the relics which had been described might be long preserved in Watt's adopted town. A few years ago those relics had nearly passed into the possession of the town; but the permission which was given was recalled, and they were retained in the room in which many of the members had seen them that day. The reasons for now securing them seemed to him to be overwhelming. The first son of James Watt, Gregory, died in early manhood; but the second son, James, survived his father, and took a most filial and reverent interest in all that his father had done. He lived many years at Aston Hall, and did all that he could, and all that the law allowed, by entailing the land and making heirlooms of the

property, so that his father's possessions might be undisturbed; and happily that had been, to a very large extent, successful. It had been a dream of some of them, nearly realised at the time to which he had referred, that it might be possible to preserve the relics of the father in the house in which the son had lived who desired them to be preserved; Aston Hall was now public property, and a perfect copy of the room might be made there. He trusted that that hope was not altogether fallacious. In any case, he begged the members to accept his personal thanks, and he was quite sure that he spoke for many in the town, for the kindly care they had bestowed upon the relics, and for the production of the drawings, &c., that had been exhibited. A fire might happen anywhere at any time, and in such a case those copies would be invaluable. He assured them from long personal knowledge that the treasures of Heathfield Hall had not yet been exhausted or fully explored. He had been very much struck by the fact that Mr. Cowper, even with his large experience, had found there a method of stiffening a frame which he had not previously seen. That was one of Watt's minor inventions—the small dust of his genius. He was quite sure, if the Institution could see its way to appoint some competent person to make a thorough overhauling of that room, they would not only be instructed by the result, but posterity would thank them for handing down still further tributes to the memory of a man who had well been called in Brougham's immortal epitaph "one of the most illustrious followers of science, and one of the greatest benefactors of the world."

Mr. W. P. Marshall hoped the suggestion which Mr. Timmins had made would be supported by everyone, both in the neighbourhood and elsewhere, and that those at a distance would not feel any jealousy; Aston Hall being public property, the relics of James Watt would be carefully preserved there, in a way which was not possible elsewhere.

Mr. Jeremiah Head, as one of those who had come from a distance, and had had the opportunity of going to Heathfield House and seeing the historical room to which reference had been made,

was not sorry to have an opportunity of saying how extremely interested he had been. One could not look through that room, with all the models &c. lying just as Watt had left them some 70 or 80 years ago, without very grave reflections. As engineers they might take comfort from seeing the way in which James Watt did his work. He had the same kind of tools and other appliances that they had all been accustomed to, though in very crude forms. They saw that he worked in a garret, extremely deficient in light, and very high up in the house,—just such a place as any one of them who had boys might apportion for them to have a lathe in. They had been accustomed, in reading and hearing of Watt, to think that he was a great genius, who had not the ordinary struggles and difficulties of life to contend with; but after looking round his room, they would be convinced that he had just the same difficulties as ordinary people. There was no royal road for him, any more than for themselves. His was a case of strong natural bent, and of energetic working under very great difficulties. They found that he was sufficiently human to make mistakes, as others did in the course of their work. He had been shown to have weak points in his character, according to modern notions: as when he made efforts to get an Act of Parliament passed to stop competitors from making high-pressure engines. The strong points were evinced in his many useful works, and in the great effects they had produced, to the benefit of all mankind. There was also a sad side to his character. It was almost pathetic to think that such a man, in his old age, was working alone in a garret, having locked himself in, so that he might not be interfered with by any members of his family who had no sympathy with his labours; and had his meals actually brought up and set upon a little shelf outside his door, so that he might not be interrupted,—taking them in at his leisure, and heating them up on his own stove. That showed how different he was even from those immediately surrounding him, and how he was therefore obliged to go quietly on his own way with very little sympathy.

With regard to the wagon boilers, just referred to by Mr. Cowper, he might say that within 20 or 30 years there were some of these still at work on Tyneside, and he was not sure that there were not

some still used as tanks. Looking generally at Watt's inventions, he thought they presented another instance of the law of the "survival of the fittest." They found that he designed and worked at all sorts of things,—such as making copying-ink,—which seemed scarcely worthy of his genius: it would have been better, they might think, if he had devoted his powers even more exclusively to the great public needs which he alone seemed capable of supplying. Watt himself however did not exactly know the way things were tending, as people now knew from what had happened. Some of the things at which he worked had produced enormous results; others seemed to have remained just as he left them. But on the whole there never perhaps was a life which had produced more enormous results for the benefit of mankind than that of James Watt.

Mr. Henry Davey said he happened to be the possessor of a letter of the immortal James Watt, which had now gained additional interest and value from Mr. Cowper's paper. The letter was in James Watt's own handwriting, to his right-hand man, William Murdock, and had reference to the copying lathe. There was in that letter something which he himself could never understand before, but which was now clear, namely, "You seem to have given the finishing blow to the roofed frame, which appears perfectly stiff." He concluded this referred to the trussed frame. It was evident from the construction of the frame that it was originally made without a truss. Some difficulty was no doubt experienced and some little trouble taken in discovering a method of making it perfectly rigid; and this method had been either suggested or carried into effect by William Murdock.

Mr. E. B. Marten called attention to the model, Figs. 9 and 10, Plate 59; it belonged to Mr. W. Westwood Skidmore, of Field Cottage, Old Swinford, who had it given him when a boy, to work a lathe with, by a relative, Mr. William Wright, who believed it to have come from Soho Works. When Mr. Skidmore knew its value, he immediately put another engine to do that work, and since that time had taken very great care of it, and lent it for exhibition at

Worcester the year before. Its history was not fully known. It stood for some time in the pattern shop of their late member, Mr. William Mathews, at the Corbyn's Hall Iron Works, near Dudley; and there might be some present who would remember the model and could give some information as to its history.*

Mr. W. S. Hall said it might be interesting to the members if he stated that there was one of Watt's double-acting rotative engines in constant work up to about two years ago, doing very good service indeed at the Tape Mill at Measham, near Ashby-de-la-Zouch. He had gone over there a few days before to get some particulars, but found to his very great disappointment that about nine months ago the engine was sold and broken up, and not a piece of it was left. Speaking from recollection, the valve-gear was worked by tappets from the air-pump rod, but could be handled separately if required. The engine was very similar in construction to Figs. 11 and 12, Plate 60, except that it had an iron beam. The cylinder was about 24 in. diameter with a 5-ft. stroke. It was steam-jacketed, and provided with a parallel motion, though this might have been a later addition. The pressure of steam was between 3 and 5 lbs. per sq. in. The boiler was, he thought, a wagon boiler. It was locally reputed to be the second double-acting rotative engine that had ever been built by James Watt; and the date on the factory bell, which was 1784, seemed to corroborate this. He might add that he had in his possession a relic which he had taken the liberty of placing on the table, namely James Watt's spectacles. He had a little pedigree showing how they came into his possession.† He also wished to

* Mr. William Barlow, of Tiled House, Pensnett, near Dudley, has since informed the Secretary that the model stood in the pattern shop at the Corbyn's Hall Works for many years; his impression is that it was presented to Mr. Attwood Mathews when a boy by one of the Attwood family, and that it originally came from and was made at the Soho Works.

† This pair of spectacles, formerly worn by James Watt, was given by him in 1818 to William Murdock, afterwards passing into the possession of his son, John Murdock, who died a bachelor, and left them to his housekeeper, Mrs. Silk, who in 1870 gave them to her son-in-law, William Biddlestone, from whom in

corroborate Mr. Cowper's statement as to the exceedingly low pressure of steam he had seen used. He had himself seen pumping engines working *below* atmospheric pressure, so that when the safety-valve of the boiler was lifted there was a slight suck-in of air.

Mr. Samuel Timmins said there was an engine not unlike Figs. 11 and 12, Plate 60, still working in Birmingham, with timber beam and ordinary parallel motion. It was at the works of Mr. Clifford in Fazeley Street. It was built about the beginning of the present century; and the late Mr. Clifford had informed him that it was the best engine he had in his works, and required very little attention even now.*

The President thought those present would agree with him that among the many interesting papers which had been brought before the Institution none had been of deeper interest to engineers than Mr. Cowper's. It was unique in its nature; and he thought he might go so far as to say that no other kindred Institution had had a more interesting paper presented to it. The large attendance of members also showed that they were desirous of doing honour to the memory of their great engineer. He was sure that Mr. Cowper did not look for any thanks for what he had done; but it was fortunate for the Institution and for the world (for the paper would go far and wide) that the work had fallen into the hands of so experienced an

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1871 they descended to his grandson, William Biddlestone, and in 1872 to the latter's cousin, Robert MacLeish, formerly one of the engineers on board the "Great Eastern" steamship. He gave them to his uncle, Robert MacLeish, by whom they were given in 1875 to their present possessor, William Silver Hall, for whom Robert MacLeish (the uncle) then worked as foreman at the Abbey Engine Works, Nuneaton.

* Mr. Arthur Clifford has since kindly informed the Secretary that this engine is still at work, and is still in remarkably good condition. It was built, not by Boulton & Watt, but by a machinist in Lionel Street, Birmingham, and was started in 1802. It has a crank, and a counter fly-wheel which runs idle. The cylinder is 50¼ in. diam. and 9 ft. stroke; the boiler pressure is 10 lbs. per sq. in. above atm.; on a late indication the engine was giving off 182 H.P., working a large rolling-mill in which there are twelve pairs of rolls.

engineer; and he called upon the members to give a hearty vote of thanks to Mr. Cowper for his exceedingly interesting paper, and for the time and trouble he had taken in preparing it. It had been stated that there was still much more to be learnt of Watt's early inventions. He hoped therefore that Mr. Cowper's labours were not ended, but that he would continue to enlarge upon the subject of his paper. He would at the same time ask the members to give votes of thanks to the Science and Art Department, South Kensington, and to Mr. George Tangye, for the photographs presented to the Institution, and for the other facilities given with respect to the models &c. of James Watt.

FIRST REPORT ON FRICTION EXPERIMENTS.

By Mr. BEAUCHAMP TOWER, of London.

(*Adopted by the Committee on Friction, and presented to the Council, Sept.* 28, 1883.)

I. Description of Machine.

In experimenting on the friction of lubricated bearings, and on the value of different lubricants, one of the difficulties which is first met with is the want of a method of applying the lubricant, which can be relied upon as sufficiently uniform in its action. All the common methods of lubrication are so irregular in their action that the friction of a bearing often varies considerably. This variation, though small enough to be of no practical importance, and to pass unnoticed, in the working of an ordinary machine, would be large enough utterly to destroy the value of a set of experiments, say, on the relative values of various lubricants; for it would be impossible to know whether an observed variation was due to a difference in the quality of the oil, or in its rate of application. The first problem therefore which presented itself, in the present experiments, was to devise a method of lubrication such as would be perfectly uniform in its action, and would form an easily reproducible standard with which to compare other methods. These conditions were best fulfilled by making the bearing run immersed in a bath of oil. By this method the bearing is always supplied with as much oil as it can possibly take; so that it represents the most perfect lubrication possible, and is a good standard with which to compare other methods. It is at all times perfectly uniform in its action. It is very easily defined and reproduced; and it also has the advantage that the temperature of the bearing can be easily regulated by gas jets under the bath. Experiment showed that the bath need not be full; the results obtained were the same when it was so nearly empty that the bottom of the journal only just touched the oil.

The journal experimented on (see Figs. 1 and 2, Plates 88 and 89) was of steel, 4 in. diameter and 6 in. long, with its axis horizontal. A gun-metal brass A, embracing somewhat less than half the circumference of the journal, rested on its upper side. The exact arc of contact of this brass was varied in the different experiments, as will be seen by reference to the appended Tables of results. Resting on this brass was a cast-iron cap B, from which was hung by two bolts a cast-iron cross-bar C carrying a knife-edge. The exact distance of this knife-edge below the centre of the journal was five inches. On this knife-edge was suspended the cradle D which carried the weight applied to the bearing. The cap, bolts, and cross-bar were put together in such a manner as to form a rigid frame, connecting the brass with the knife-edge. If there had been no friction between the brass and the journal, the weight would have caused the knife-edge to hang perpendicularly below the axis of the journal. Friction however caused the journal to tend to carry the brass, and the frame to which it was attached, round with it, until the line through the centre of journal and the knife-edge made such an angle with the perpendicular that the weight multiplied by the distance from the knife-edge to that perpendicular offered an opposing moment just equal to the moment of friction.

Suppose r = radius of the journal (Fig. 3, Plate 88).
s = distance of the knife-edge from the perpendicular.
w = the weight.

Then, from above, $s \times w$ = the moment of friction.

Now the friction at the surface of the journal

$$= \frac{\text{the moment}}{r} = \frac{w \times s}{r}.$$

Hence the coefficient of friction $= \dfrac{\text{Friction at surface of journal}}{w} = \dfrac{s}{r}.$

So that the coefficient of friction is indicated by s in terms of r, no matter what the weight is. As an example, suppose s was equal to r; the coefficient of friction would obviously be 1; or if s was $\frac{1}{10}$ of r, then the coefficient of friction would be $\frac{1}{10}$.

In order to avoid the difficulty of determining accurately when

the knife-edge was perpendicularly under the centre of the journal (a knowledge which was necessary in order to obtain a measurement of s, and which was very difficult to obtain owing to the considerable friction between the brass and the journal when at rest), each experiment was tried with the journal revolving in both directions, and the sum of the values of s on both sides was measured; and then the coefficient of friction was indicated by the chord of the whole angle, included between the two lines of inclination caused by the friction, with the rotation in the two directions, the chord being expressed in terms of the diameter of the journal (see Fig. 4, Plate 88). Each result was thus a mean of two experiments, one with the axle running in one direction, and the other with it running in the other direction. In order to read the value of the coefficients thus obtained, a light horizontal lever L was attached (as shown in Fig. 1) to the frame connecting the brass to the knife-edge. It was $62\frac{1}{2}$ inches long, or $12\frac{1}{2}$ times the distance between the centre of the journal and the knife-edge; so that at the end of the lever the chord indicating the coefficient of friction was magnified $12\frac{1}{2}$ times. As a chord of 4 inches at the knife-edge represents a coefficient of 1, a chord of 50 inches at the end of the lever also represents a coefficient of 1, while 5 inches represents a coefficient of $\frac{1}{10}$, $\frac{1}{2}$-inch of $\frac{1}{100}$, and $\frac{1}{20}$-inch of $\frac{1}{1000}$. The position of the end of the lever during each experiment was recorded by a tracing point attached to the end of the lever, and marking on metallic paper carried upon a revolving vertical cylinder P. The distance between the two lines obtained by running the axle both ways, when measured on the above scale, indicated the value of the coefficient.

II. Method of Experimenting.

Early in the experiments it was found that, immediately after the motion of the shaft was reversed, the friction was greater than it was when the shaft had been running in the same direction some time. This increase of friction, due to reversal, varied considerably. It was greatest with a new brass, and diminished as the brass became worn, so as to fit the journal more perfectly. Its greatest observed

amount was at starting and was about twice the normal friction, and it gradually diminished until the normal friction was reached after about ten minutes continuous running. This increase of friction was accompanied by a strong tendency to heat and seize, even under a moderate load. In the case of one brass, which had worked for a considerable time without accident, and had consequently become worn so as to fit the journal very accurately, this tendency to increase of friction after reversal almost entirely disappeared; and it could be reversed under a full load without appreciable increase of friction or a tendency to heat or seize. The phenomenon must be due to the surface fibres of the metal, which have been for some time stroked in one direction, meeting point to point and interlocking when the motion is reversed. The very perfectly fitting brass was probably entirely separated from the journal by a film of oil; and there being no metallic contact the phenomenon did not show itself. In consequence of the above facts, it was found necessary to proceed with the experiments in the following order. A complete series of experiments, with a gradually increasing load, was taken with the journal running in one direction; the load was then diminished by the same steps as it had been increased, and the experiments thus repeated, the shaft still running in the same direction, until the load had thus been reduced to 100 lbs. per sq. in., which was the load due to the unweighted cradle. The direction of motion was then reversed, and the shaft run for half-an-hour, so as to get it thoroughly used to going the other way; after this the load could be increased and the experiments taken without any difficulty. The experiments, as before, were taken at each step of both increasing and decreasing the load; so that each recorded result is really the mean of four experiments, which have in many instances been taken several hours apart.

This method of obtaining a direct indication of the coefficient of friction, by the angular displacement of the frame connecting the brass and knife-edge, would undoubtedly have been the best had the coefficient of friction been nearly as constant as it has hitherto been supposed to be. But as shown by the Tables of results, the coefficient

of friction was found, instead of being constant, to vary nearly inversely as the load, and also to be much smaller in quantity than was expected; the consequence was that with high loads the height of the diagram was very small. In the cases where with the greatest loads a coefficient of only $\frac{1}{1000}$ was observed, the distance between the two lines was only $\frac{1}{20}$ inch.

The results shown in Tables I., II., III., IV., were obtained in this way.

Owing to these experiments showing that the moment of friction was much more nearly constant than the coefficient, it was resolved to alter the method of observation, and to measure the moment directly instead of the coefficient. For this purpose the paper cylinder was removed, and a small lever M (see Fig. 1A, Plate 88) was connected to the main indicating lever in such a manner that the motion of the end of the main lever was magnified five times at the end of the small lever. The end of the small lever was pointed; and when the machine was working, this point was brought exactly opposite a fixed mark by putting weights into a scale-pan on the end of the main lever. The main lever was so overbalanced that under all circumstances some weight was required to be added in the scale-pan, in order to bring the end of the small lever to the mark, even when, in addition to the friction being greatest, the direction of motion of the journal tended most to depress it. The method of running in both directions, and loading and unloading, was followed as before. The weights in the scale-pan being noted, the moment of friction was given by half the difference between the weights in the scale-pan when running in one direction and in the other. The results given in Tables V., VI., VII., VIII., were obtained in this manner.

Experiment showed that the friction varied considerably with temperature (see Table IX.) All the oil-bath experiments were therefore taken at a nearly uniform temperature of 90°; the variation above or below this temperature was never allowed to be more than $1\frac{1}{2}$°.

III. Results of Experiments.

In the experiments shown in Tables I., II., and III., care was taken not to load the bearing up to seizing, in order that the condition of the brass might not be disturbed.

In Table IV. the bearing seized unintentionally.

In Tables V., VI., VII., and VIII., the bearing was intentionally loaded up to seizing.

The experiments shown in Tables V. and VI. were specially made for the purpose of ascertaining the greatest load which could be carried with rape and mineral oil in the oil bath. The greatest load carried with the rape oil was 573 lbs. per. sq. in., and the greatest load carried with the mineral oil was 625 lbs. In both of these cases the experiment was repeated after the brass had been taken out and scraped up, but with no better result.

The general results of the oil-bath experiments may be described as follows. The absolute friction, that is the actual tangential force per sq. in. of bearing, required to resist the tendency of the brass to go round with the journal, is nearly a constant under all loads, within ordinary working limits. Most certainly it does not increase in direct proportion to the load, as it should do according to the ordinary theory of solid friction. The ordinary theory of solid friction is that it varies in direct proportion to the load; that it is independent of the extent of surface; and that it tends to diminish with an increase of velocity beyond a certain limit. The theory of liquid friction, on the other hand, is that it is independent of the pressure per unit of surface, is directly dependent on the extent of surface, and increases as the square of the velocity. The results of these experiments seem to show that the friction of a perfectly lubricated journal follows the laws of liquid friction much more closely than those of solid friction. They show that under these circumstances the friction is nearly independent of the pressure per sq. in., and that it increases with the velocity, though at a rate not nearly so rapid as the square of the velocity.

The experiments on friction at different temperatures, shown in Table IX., indicate a very great diminution in the friction as the

temperature rises. Thus, in the case of lard oil, taking a speed of 450 revolutions per minute, the coefficient of friction at a temperature of 120° is only one-third of what it was at a temperature of 60°.

A very interesting discovery was made when the oil-bath experiments were on the point of completion. The experiments being carried on were those on mineral oil; and the bearing having seized with 625 lbs. per sq. in., the brass was taken out and examined, and the experiment repeated. While the brass was out, the opportunity was taken to drill a ½-in. hole for an ordinary lubricator through the cast-iron cap and the brass. On the machine being put together again and started with the oil in the bath, oil was observed to rise in the hole which had been drilled for the lubricator. The oil flowing over the top of the cap made a mess, and an attempt was made to plug up the hole, first with a cork and then with a wooden plug. When the machine was started the plug was slowly forced out by the oil in a way which showed that it was acted on by a considerable pressure. A pressure-gauge was screwed into the hole, and on the machine being started the pressure, as indicated by the gauge, gradually rose to above 200 lbs. per sq. in. The gauge was only graduated up to 200 lbs., and the pointer went beyond the highest graduation. The mean load on the horizontal section of the journal was only 100 lbs. per sq. in. This experiment showed conclusively that the brass was actually floating on a film of oil, subject to a pressure due to the load. The pressure in the middle of the brass was thus more than double the mean pressure. No doubt if there had been a number of pressure-gauges connected to various parts of the brass, they would have shown that the pressure was highest in the middle, and diminished to nothing towards the edges of the brass.

The experiments with ordinary lubrication were begun with a needle lubricator, the hole from which penetrated to the centre of the brass. A groove in the middle of the brass, and parallel to the axis of the journal, extended nearly to the ends of the bearing for distributing the oil (see Figs. 5 and 6, Plate 90). It was found that with this arrangement the bearing would not run cool when loaded with only 100 lbs. per. sq. in.; and that not a drop of oil

would go down even when the needle-lubricator was removed and the hole filled completely with oil, thus giving a head of 7 inches of oil to force it into the brass. It appeared as though the hole and groove, being in the centre of pressure of the brass, allowed the supporting oil-film to escape. This view was confirmed by the following experiment. The oil-hole being filled up to the top, the weight was eased off the journal for an instant. This allowed the oil to sink down in the hole and lubricate the journal; but immediately the load was again allowed to press on the journal the oil rose in the hole to its former level, and the journal became dry, thus showing that this arrangement of hole and groove, instead of being a means of lubricating the journal, was a most effectual one for collecting and removing all oil from it. It should be mentioned that care was taken to chamfer the edges of the groove, so as to prevent any scraping action between them and the journal.

As the centre of the brass was obviously the wrong place to introduce the oil, it was resolved to try to introduce it at the sides. Accordingly the centre hole and groove were filled up, and two grooves were made. These grooves were parallel to the axis of the journal, extending nearly to the ends of the brass, and were placed at equal distances on either side of the centre; they formed boundaries to an arc of contact, the chord of which was 3¼ in. (see Figs. 7 and 8, Plate 90). With this arrangement of groove the lubrication appeared to be satisfactory, the oil going down into the journal and the bearing running cool. The results of the experiments with this arrangement of brass are given in Table VII. The bearing nevertheless seized with an actual load of only 380 lbs. per sq. in.

The arrangement of grooves was then altered to that usual in locomotive axle-boxes (see Figs. 9–11, Plate 89). The oil was introduced through two holes, one near each end of the brass, and each connected to a curved groove; the two curved grooves nearly enclosing an oval-shaped space in the centre of the brass. At the same time the arc of contact was reduced till its chord was only 2¼ in. This brass refused to take its oil or run cool. It would sometimes run for a short time with an actual load of 178 lbs. per

sq. in., but rapidly heated on the slightest increase of the load. The brass having been a good deal cut about by altering and filling up grooves, it was considered desirable to have a new brass, and one was accordingly obtained. The grooves being made exactly the same as in the last experiment with the old one, this brass seized with an actual load of only about 200 lbs. per sq. inch. The oil-box was completely cut away so as to allow a freer current of air round the bearing, and the lubricator pipes were soldered into the brass. The wicks were taken out of the lubricators and the lubricators filled full of oil, by which means oil was supplied to the brass under a full head of 9 in.; and yet the oil refused to go down, and the underside of the journal felt perfectly dry to the hand, and speedily heated with a load of only 200 lbs. per. sq. in.

The fact that this arrangement of grooves, which is found to answer in the axles of railway vehicles, was found to be perfectly useless in this apparatus, can only be accounted for by the fact that a railway axle has a continual end play while running, which prevents the brass from becoming the perfect oil-tight fit which it became in this apparatus. The attempts to make this arrangement of lubrication answer were not abandoned until after repeated trials. It now became clear that there was no use in trying to introduce the oil directly to the part of the brass against which the pressure acted, and that the only way to proceed was to oil the lower side of the journal, and trust to the oil being carried round by the journal to the seat of the pressure.

The grooves and holes in the brass were accordingly filled up, and an oily pad, contained in a tin box full of rape oil, was placed under the journal, so that the journal rubbed against it in turning. The pad was only supplied with oil by capillary attraction from the oil in the box, and the supply of oil to the journal was thus very small; the oiliness in fact was only just perceptible to the touch, but it was evenly and uniformly distributed over the whole journal. The results are given in Table VIII. The bearing fairly carried 551 lbs. per sq. in., and three observations were obtained with 582 lbs., but the bearing was on the point of seizing and did seize after running a few minutes with this load. It will be observed that in this instance

the bearing seized with very nearly the same load as it did in the oil-bath experiment with rape oil.

These experiments with the oily pad show a nearer approach to the ordinarily received laws of solid friction than any of the others. The coefficient is approximately constant, and may be stated as about $\frac{1}{100}$ on an average. There does not in this case appear to be any well-defined variation of friction with variations of speed, according to any regular law.

The results of the experiments with rape oil, fed by a syphon lubricator to side grooves (Table VII.), follow nearly the same law as the results obtained from the oil-bath experiments, as far as the approximate constancy of the moment of friction is concerned; but the amount of the friction is about four times the amount in the oil-bath.

It should be stated that though only these two Tables are given as the results of the experiments on what is called ordinary lubrication, that is, lubrication by means other than that of the oil-bath, they represent only a small part of the experiments or attempts at experiments which were made on this subject. But they are the only experiments the results of which were sufficiently regular to make them worthy of record. Indeed the results, generally speaking, were so uncertain and irregular that they may be summed up in a few words. The friction depends on the quantity and uniformity of distribution of the oil, and may be anything between the oil-bath results and seizing, according to the perfection or imperfection of the lubrication. The lubrication may be very small, giving a coefficient of $\frac{1}{100}$; but it appeared as though it could not be diminished and the friction increased much beyond this point without imminent risk of heating and seizing. The oil-bath probably represents the most perfect lubrication possible, and the limit beyond which friction cannot be reduced by lubrication; and the experiments show that with speeds of from 100 to 200 ft. per minute, by properly proportioning the bearing-surface to the load, it is possible to reduce the coefficient of friction as low as $\frac{1}{1000}$. A coefficient of $\frac{1}{500}$ is easily attainable, and probably is frequently attained, in ordinary engine-bearings in which the direction of the force is rapidly alternating and the oil given an

opportunity to get between the surfaces, while the duration of the force in one direction is not sufficient to allow time for the oil-film to be squeezed out. The extent to which the friction depends on the quantity of the lubrication is shown in a remarkable manner in Table X.; which proves that the lubrication can be so diminished that the friction is seven times greater than it was in the oil bath, and yet that the bearing will run without seizing.

Observations on the behaviour of the apparatus gave reason to believe that with perfect lubrication the speed of minimum friction was from 100 to 150 feet per minute; and that this speed of minimum friction tended to be higher with an increase of load, and also with less perfect lubrication. By the speed of minimum friction is meant that speed in approaching which, from rest, the friction diminishes, and above which the friction increases.

TABLE I.—BATH OF OLIVE OIL. TEMPERATURE 90° F. 4-IN. JOURNAL, 6 IN. LONG. CHORD OF THE ARC OF CONTACT = 3·92 IN.

* Nominal LOAD Lbs. per sq. in.	COEFFICIENTS OF FRICTION, for speeds as below.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.								
520		·0008	·001	·0012	·0013	·0014	·0015	·0017
468		·0011	·0013	·0014	·0015	·0017	·0018	·002
415		·0012	·0014	·0015	·0017	·0019	·0021	·0024
363		·0013	·0016	·0017	·0019	·002	·0022	·0025
310		·0015	·0017	·0019	·0021	·0022	·0024	·0027
258	·0014	·0017	·002	·0023	·0025	·0026	·0029	·0031
205	·0018	·0021	·0025	·0028	·003	·0033	·0036	·004
153	·0023	·003	·0035	·004	·0044	·0047	·005	·0057
100	·0036	·0045	·0055	·0063	·0069	·0077	·0082	·0089

The above coefficients × the nominal load = nominal frictional resistance per sq. inch of bearing.

* Nominal LOAD. Lbs. per sq. in.	NOMINAL FRICTIONAL RESISTANCE per sq. in. of bearing.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
520		·416	·520	·624	·675	·728	·779	·883
468		·514	·607	·654	·701	·794	·841	·935
415		·498	·580	·622	·705	·787	·870	·995
363		·472	·580	·616	·689	·725	·798	·907
310		·464	·526	·588	·650	·680	·742	·835
258	·361	·438	·515	·592	·644	·669	·747	·798
205	·368	·43	·512	·572	·613	·675	·736	·818
153	·351	·458	·535	·611	·672	·718	·764	·871
100	·36	·45	·55	·63	·69	·77	·82	·89

* The nominal load per sq. in. is the total load divided by (4 × 6).

TABLE II.—Bath of Lard Oil. Temperature 90° F. 4-in. Journal, 6-in. long. Chord of arc of contact of brass = 3·92 in.

Nominal LOAD Lbs. per sq. in.	Coefficients of Friction, for speeds as below.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.								
520		·0009	·001	·0011	·0013	·0015	·0015	·0017
415		·0012	·0014	·0015	·0016	·0018	·0019	·0021
310		·0014	·0017	·002	·0022	·0025	·0026	·0029
205	·0017	·0020	·0023	·0028	·0031	·0034	·0039	·0042
153	·0022	·0027	·0032	·0037	·0041	·005	·0051	·0052
100	·0035	·0042	·005	·006	·0067	·0076	·0081	·009

The above coefficients × the load = nominal frictional resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	Nominal Frictional Resistance per sq. in. of bearing.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
520		·468	·52	·572	·675	·779	·779	·883
415		·498	·58	·621	·663	·746	·788	·870
310		·434	·526	·619	·680	·774	·804	·898
205	·348	·409	·47	·572	·634	·696	·798	·859
153	·336	·412	·489	·565	·626	·764	·779	·795
100	·35	·42	·5	·6	·67	·76	·81	·9

TABLE III.—Bath of Mineral Grease. Temperature 90° F. 4-in. Journal, 6 in. long. Chord of arc of contact of brass = 3·92 in.

Nominal LOAD Lbs. per sq. in.	Coefficients of Friction, for speeds as below.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.								
625		·001	·0012	·0014	·0014	·0016	·0018	·002
520		·0014	·0016	·0018	·0019	·002	·0021	·0022
415		·0016	·0019	·0021	·0023	·0025	·0026	·0027
310	·002	·0022	·0026	·0029	·0032	·0035	·0038	·004
205	·0026	·0031	·0040	·0047	·0053	·0058	·0062	·0066
153	·0028	·0038	·0048	·0057	·0065	·0071	·0077	·0083
100	·0054	·0076	·0094	·0109	·0123	·0133	·0142	·0151

The above coefficients × the nominal load = nominal frictional resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	Nominal Frictional Resistance per sq. in. of bearing.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
625		·625	·75	·875	·875	·999	1·125	1·25
520		·727	·831	·935	·987	1·04	1·091	1·143
415		·663	·787	·87	·953	1·036	1·074	1·12
310	·62	·682	·805	·899	·992	1·085	1·18	1·24
205	·531	·696	·818	·962	1·085	1·188	1·27	1·35
153	·428	·581	·734	·871	·994	1·085	1·177	1·27
100	·54	·76	·94	1·09	1·123	1·33	1·42	1·51

TABLE IV.—Bath of Sperm Oil. Temperature 90° F. 4-in. Journal, 6 in. long. Chord of arc of contact of brass = 3·92 in.

Nominal LOAD Lbs. per sq. in.	Coefficients of Friction, for speeds as below.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.								
520	Seized							
415		·0015	·0017	·0018	·0019	·002	·0021	·0021
310		·0011	·0012	·0014	·0016	·0017	·0018	·0019
205	·0013	·0016	·0018	·0021	·0023	·0024	·0025	·0027
153	·0016	·0019	·0023	·0028	·0030	·0033	·0035	·0037
100	·0025	·003	·0038	·0044	·0051	·0057	·0061	·0064

The above coefficients × the nominal load = nominal friction resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	Nominal Frictional Resistance per sq. in. of bearing.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
520	Seized							
415		·621	·705	·746	·788	·829	·87	·87
310		·341	·372	·434	·495	·526	·557	·588
205	·266	·327	·368	·43	·471	·491	·512	·552
153	·244	·291	·352	·428	·459	·505	·535	·566
100	·25	·3	·38	·44	·51	·57	·61	·64

TABLE V.—BATH OF RAPE OIL. TEMPERATURE 90° F. 4-IN. JOURNAL, 6 IN. LONG. CHORD OF ARC OF CONTACT OF BRASS = 3·92 IN.

Nominal LOAD Lbs. per sq. in.	COEFFICIENTS OF FRICTION, for speeds as below.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs. 573		·00102	·00108	·00118	·00126	·00132	·00139	
520		·000955	·00105	·00115	·00125	·00133	·00142	·00148
415		·00093	·00107	·00119	·0013	·00140	·00149	·00158
363		·00084	·0096	·0011	·00122	·00134	·00147	·00155
258	·00107	·00139	·00162	·00178	·00195	·00213	·00227	·00243
153	·00162	·0020	·00239	·00267	·003	·00334	·00367	·00396
100	·00277	·00357	·00423	·00503	·00576	·00619	·00663	·00714

The above coefficients × the nominal load = nominal frictional resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	NOMINAL FRICTIONAL RESISTANCE per sq. in. of bearing.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
Lbs.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
573		·583	·62	·678	·721	·758	·794	
520		·496	·546	·597	·648	·691	·735	·771
415		·386	·445	·495	·539	·582	·619	·655
363		·306	·35	·401	·444	·488	·532	·561
258	·277	·357	·416	·459	·503	·547	·583	·626
153	·248	·306	·364	·408	·459	·510	·561	·605
100	·277	·357	·423	·503	·576	·619	·663	·714

N.B.—The bearing seized on reversing with 573 lbs. per square inch. The experiment was repeated, but the bearing refused to carry more weight. These quantities were obtained by a direct load on the lever, so that in these the coefficient is calculated from the force on the lever, instead of the force on the lever being calculated from the coefficient as was the case in the former experiments.

TABLE VI.—Bath of Mineral Oil. Temperature 90° F. 4-in. Journal, 6 in. long. Chord of arc of contact of brass = 3·92 in.

Nominal LOAD Lbs. per sq. in.	Coefficients of Friction, for speeds as below.						
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.
Lbs. 625		·0013	·00139	·00147	·00157	·00165	
520		·00123	·00139	·0015	·00161	·0017	·00178
415		·00123	·00143	·0016	·00176	·0019	·002
310		·00142	·0016	·00184	·00207	·00225	·00241
205	·00178	·00205	·00235	·00269	·00298	·00328	·0035
100	·00334	·00415	·00494	·00557	·0062	·00676	·0073

The above coefficients × the nominal load = nominal frictional resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	Nominal Frictional Resistance per sq. in. of bearing.						
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.
Lbs.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
625		·81	·865	·92	·98	1·03	
520		·64	·72	·782	·84	·886	·924
415		·51	·594	·664	·73	·785	·83
310		·44	·494	·57	·64	·695	·745
205	·364	·419	·48	·55	·61	·67	·716
100	·334	·415	·494	·557	·62	·676	·73

N.B.—The bearing carried the 625 lbs. per sq. in. running both ways, but seized on the weight being increased.

These quantities were obtained by a direct load on the lever, as in Table V.

This was a thinner sample of mineral oil than that used in the previous experiments; it was fluid at 50°, while the oil previously used could only be described as grease at 50°. This will account for these experiments showing less friction than the former, except with the highest load, at which, the thin oil being overloaded and on the point of seizing, the friction is greater than with the thick oil.

TABLE VII.—Rape Oil, fed by syphon lubricator.

4-in. Journal, 6 in. long. Chord of arc 3¼ in.

Nominal LOAD Lbs. per sq. in.	Actual LOAD Lbs. per sq. in.	Coefficients of Friction, for speeds as below.						
		100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.
Lbs. 258	Lbs. 317		·0056	·0057	·0063	·0068		
205	252	·0132	·0098	·007	·0077	·0082	·0087	
100	123	·0144	·0125	·0146	·0152	·0163	·0171	·0178

The above coefficients × the nominal load = nominal frictional resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	Actual LOAD Lbs. per sq. in.	Nominal Frictional Resistance per sq. in. of bearing.						
		100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.
Lbs. 258	Lbs. 317	Lb.	Lb. 1·43	Lb. 1·46	Lb. 1·61	Lb. 1·76	Lb.	Lb.
205	252	2·71	2·01	1·43	1·57	1·68	1·79	
100	123	1·44	1·25	1·46	1·52	1·63	1·71	1·78

The chord of the arc of contact of the brass = 3¼ in.

The nominal load per sq. in. is the total load divided by 4 × 6.

The actual load per sq. in. is the total load divided by 3¼ × 6.

The bearing seized on attempting to run with an actual load of 380 lbs. per sq. in.

With nominal load of 258 lbs. per sq. in. the temperature of the bearing was 90°.
" " " 205 " " " " 85°.
" " " 100 " " " " 80°.

TABLE VIII.—Rape Oil, pad under Journal. 4-in. Journal, 6 in. long. Chord of arc of contact of brass = $2\frac{1}{4}$ in.

Nominal LOAD Lbs. per sq. in.	Actual LOAD Lbs. per sq. in.	Temperature. Fahr.	Coefficients of Friction, for speeds as below.						
			100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.
328	582	90°			·0107	·0102	·0098		
310	551	82°		·0099	·0099	·0092	·0099		
293	520	76°		·0105	·0105	·0097	·0097		
275	498	77°		·0091	·0091	·0095	·0103		
258	458	78°		·0112	·0095	·0088	·0084	·0082	·0083
205	364	82°		·0105	·0087	·0085	·0078	·0085	·01
153	272	74°	·0102	·009	·0096	·0102	·0105	·0119	·0125
100	178	75°	·0105	·0099	·0109	·0122	·0133	·0144	·0154

The above coefficients × the nominal load = nominal frictional resistance per sq. in. of bearing.

Nominal LOAD Lbs. per sq. in.	Actual LOAD Lbs. per sq. in.	Temperature. Fahr.	Nominal Frictional Resistance per sq. in. of bearing.						
			100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.
			Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
328	582	90°			3·5	3·35	3·21		
310	551	82°		3·06	3·06	2·84	3·06		
293	520	76°		3·06	3·06	2·84	2·84		
275	498	77°		2·49	2·49	2·62	2.84		
258	458	78°		2·89	2·44	2·28	2·17	2·1	2·13
205	364	82°		2·145	1·78	1·735	1·605	1·75	2 04
153	272	74°	1·56	1·37	1·473	1·56	1·605	1·81	1·89
100	178	75°	1·0	0·992	1·093	1·225	1·33	1·44	1·54

The chord of the arc of contact of the brass = $2\frac{1}{4}$ in.

The nominal load per sq. in. is the total load divided by 4 × 6.

The actual load per sq. in. is the total load divided by $2\frac{1}{4}$ × 6.

The results with the actual load of 582 lbs. per sq. in. were obtained with difficulty, and the bearing seized with that load after running for a short time.

The pad consisted of a piece of felt pressing against the journal, and resting on worsted immersed in a tin box full of oil.

TABLE IX.—Bath of Lard Oil. Variation of Friction with Temperature. Nominal Load 100 lbs. per sq. in.

Temperature Fahr.	Coefficients of Friction, for speeds as below.							
	100 rev. 105 ft. per min.	150 rev. 157 ft. per min.	200 rev. 209 ft. per min.	250 rev. 262 ft. per min.	300 rev. 314 ft. per min.	350 rev. 366 ft. per min.	400 rev. 419 ft. per min.	450 rev. 471 ft. per min.
120°	·0024	·0029	·0035	·004	·0044	·0047	·0051	·0054
110°	·0026	·0032	·0039	·0044	·005	·0055	·0059	·0064
100°	·0029	·0037	·0045	·0051	·0058	·0065	·0071	·0077
90°	·0034	·0043	·0052	·006	·0069	·0077	·0085	·0093
80°	·004	·0052	·0063	·0073	·0083	·0093	·0102	·0112
70°	·0048	·0065	·008	·0092	·0103	·0115	·0124	·0133
60°	·0059	·0084	·0103	·0119	·013	·014	·0148	·0156

TABLE X.—Comparison of the Friction with the different Methods of Lubrication, under as nearly as possible the same circumstances. Lubricant Rape Oil, Speed 150 revolutions per min.

	Actual LOAD Lbs. per sq. in.	Coefficient of Friction.	Comparative Friction.
Oil Bath	263	·00139	1
Syphon lubricator	252	·00980	7·06
Pad under journal . . .	272	·00900	6·48

TABLE XI.—Comparison of the Friction with the various Lubricants tried, under as nearly as possible the same circumstances. Temperature 90°, Lubrication by Oil Bath.

Lubricant.	Mean Resistance.	Per Cent.
	Lb.	
Sperm Oil	0·484	100
Rape Oil	0·512	106
Mineral Oil	0·623	129
Lard Oil	0·652	135
Olive Oil	0·654	135
Mineral Grease . . .	1·048	217

N.B.—The above figures (calculated from Tables I.–VI.) are the means of the actual frictional resistances at the surface of the journal per sq. in. of bearing, at a speed of 300 revs. per min., with all nominal loads from 100 lbs. per sq. in. up to 310 lbs. per sq. in.

They also represent the relative thickness or body of the various oils, and also in their order, though perhaps not exactly in their numerical proportions, their relative weight-carrying power. Thus sperm oil, which has the highest lubricating power, has the least weight-carrying power; and though the best oil for light loads, would be inferior to the thicker oils if heavy pressures or high temperatures were to be encountered.

Abstract of Discussion on Friction Experiments.

Mr. William Anderson said that the experiments were extremely important, especially to those who had to do with heavy machinery, and who found sometimes that the proportions they had assigned to bearings had not answered their expectations. It was a great puzzle to know why such proportions sometimes answered and sometimes did not. With regard to the method of lubrication from beneath, it was used to a considerable extent in the axles of railway wagons; and in bearings exposed to very high pressure, but at very low speeds—namely the axles of the wheels of travelling cranes—he had found that by lubricating the axles from beneath, by a sponge or wick dipping into a cistern of oil, the bearings wore much better than in any other way. If the oil, when put in from the top, could not get down in an apparatus so well constructed and cared for as the one described, much more could it not get down in the case of a travelling crane, where the oil holes were liable to get stopped up with dust and dirt. He hoped that the Institution would continue the experiments, and by degrees arrive at something like a general law as a guide in such matters.

Mr. J. H. Wicksteed said that the highest pressure attained in the experiments was, as he understood, 625 lbs. per sq. in., and the minimum of friction was reached at a speed of from 100 to 150 feet per minute. He should have expected to find that with a slower speed the surfaces would not seize even at a much higher pressure. Punching and shearing machines worked with their eccentric pins under a pressure of some tons to the inch, and went on working quite cool. They were however working under the favourable circumstances mentioned in the paper, namely that the pressure alternated; the shaft was relieved from the bottom, went round the top and gathered oil, and came down to the bottom again with a fresh film of lubricant. There would be much interest in knowing at what pressure a bearing would seize, if working at a very slow rate, something like 20 feet per minute.

Mr. John Robinson wished to draw attention to page 641, in which it was stated, "The oil-bath probably represents the most perfect lubrication possible, and the limit beyond which friction cannot be reduced by lubrication." The oil-bath was a very difficult thing to work in practice; but the experiment described on page 632 showed that the bath need not be full, and that the results obtained were the same when it was so nearly empty that the bottom of the journal only just touched the oil. It appeared to him that that indicated a very practicable mode of applying lubrication to shafts in nearly all circumstances, without having the waste which must accrue from a complete bath of oil.

Mr. Henry Davey said he could bear out what Mr. Wicksteed had stated with regard to much higher pressures being used than those mentioned in the paper. In slow-running pumping engines he often used 600 lbs. per sq. in., and he knew that in many places, where it was not convenient to make a bearing very large, the pressure was over 1000 lbs., without any trouble whatever occurring. When slow speeds were used (say up to 12 ft. per min.) it was possible to go to high pressures. In such cases the pressure was generally intermittent; but in the case of shafts for pump-rod quadrants it was not intermittent. The pressure was always in the same direction, and there was no tendency to lift the bearing, and so allow the oil to get underneath. In that case the pressure he adopted was often 600 lbs. per sq. in., and he had no difficulty whatever with it.

Mr. Arthur Paget thought the discussion they had heard showed that the Committee who had investigated this subject were certainly doing good work. They had already worked out a series of experiments upon friction at high speeds and great pressures, with continuous friction and proper lubrication. It should be understood that proper lubrication did not necessarily imply a bath that covered half the journal, but that some part of the journal should run in oil. These experiments had shown that the laws of friction of such journals more closely approximated to the laws of liquid friction than to the laws of solid friction as had been hitherto supposed.

Those gentlemen who mentioned cases of very high pressures—Mr. Wicksteed and Mr. Davey—had shown that a great deal depended on the friction being intermittent; and that again appeared as if the laws of liquid friction applied in these cases instead of those of solid friction, which would account for these cases bearing such extreme pressures. Some years ago the same subject was mentioned by a former President of the Institution, now present—Mr. Hawksley,—who said he had formerly been puzzled by certain cases where the friction proved to be much less than had been expected. His explanation was that the friction in these cases was really "dithering" friction, as if you frequently struck a table underneath while you dragged a weight over the top. There was then a vibration set up, so that part of the time there was friction, and part of the time the weight was partially relieved or even in the air; and he ventured to think that, whatever more scientific terms, such as intermittent friction, they might apply, this "dithering friction" was at the bottom of many of the unexpected differences in friction that had been discovered. He earnestly hoped that the Committee would carry the experiments further, both with smaller bearings, and also, if possible, with bearings having a little end-play, such as ordinary railway axles and many other axles had.

Mr. Henry Lea said some years ago he had a 5-inch back-geared screw-cutting lathe, which had a hardened steel mandril about 1¼ in. in diameter, with a length of hardened steel bearing about the same; and he found that this lathe could be treadled with the utmost ease as long as the upper part of the bearing, which was a split collar, was down in its place upon the mandril; but if he took off the upper part, the bearing might be lubricated to any extent, yet it was absolutely impossible to treadle the lathe. It struck him as being very curious, and he did not know whether it was to be explained on the principles now discussed.

Professor R. H. Smith asked what sort of journal it was that was experimented upon; whether it was an overhanging journal, or one supported at both ends. That was an important matter,

because all overhanging journals had necessarily the bearing pressure unequally distributed over their length, to some extent. The method of measuring friction by the tilting to one side of a hanging weight was that used by Prof. Thurston in America; but he should like to know whether the experimenters got the pointer upon the paper to stand steadily. He knew how rapidly the coefficient of friction varied with many minute variations of circumstances, and he did not exactly see how a slight swinging of the weight could be avoided, or how the pointer could be kept quite steady.

The open brass represented one class of bearings largely used, but it could not at all represent the condition of lubrication of the majority of the bearings used in machinery. He would also ask whether the oil bath applied from the top was equally efficient with the oil bath applied from the bottom. Mr. Lea's result was probably due to want of steadiness of the spindle, resulting from the removal of the cap. It appeared almost impossible to avoid the conclusion that an open surface anywhere on a shaft, opposite to the side to which the bearing pressure was applied, should be equally efficient as a surface to which to apply the oil.

No doubt the members of the Committee were quite familiar with the results obtained by Prof. Thurston, who had shown that the coefficient of friction diminished very greatly with the increase of pressure per square inch; and in some of his tables of results it was shown that the coefficient went down at a very much more rapid rate than the pressure increased, so that there was actually less total friction with a greater pressure than with a smaller. The statement in p. 642 of the paper, "that this speed of minimum friction tended to be higher with an increase of load," was also deducible from Prof. Thurston's experiments. There was likewise a great variation of friction with the temperature of the bearing, and Prof. Thurston had endeavoured to find out the law according to which that variation took place. There was found to be a temperature at which the friction was a minimum, which temperature was different for different speeds, and also for different pressures. The coefficient increased very rapidly with the temperature at a slow speed, whereas at high speeds it varied in exactly the opposite way. He hoped it would be mentioned whether

the pressure stated in the tables was measured per sq. in. of the diametral sectional area or of the circumferential area. At the Mason Science College he had almost completed an apparatus for testing journal-friction with different oils, in which there was no bending pressure upon the journal at all. The apparatus was so supported, the pressure being put on two sides of the journal equally, and the whole weights were so adjusted, that the journal was not bent by any force whatever.

Mr. Druitt Halpin said the question of friction where the pressures were intermittent or constant could not be better illustrated than by the case of a locomotive. Taking the *Lady of the Lake* engine, as illustrated in Colburn's Locomotive Engineering, the crank-pins were 3½ by 3 in., giving 10½ sq. in. area; and the cylinder area being 201 sq. in., at 140 lbs. pressure per sq. in. it would be found there was a total load of 28,140 lbs. on each crank-pin, or 2680 lbs. per sq. in. But that was only an instantaneous pressure at the commencement of the stroke, and was calculated without taking into consideration the modifying effect due to the weight of the reciprocating parts; besides which this pressure was alternating in its direction. On the other hand, in the same engine the main bearings were 6 in. by 6 in., or 36 sq. in., and assuming they each carried a load of 8 tons, that gave only 498 lbs. pressure per sq. in. But this pressure was constant in direction and intensity; and if any such pressure as the former were attempted to be put on the main bearings, they all knew what result to expect.

Mr. E. A. Cowper wished to mention a plan of lubrication, which he had seen at Messrs. Rennie's works, and which seemed to be admirable, particularly for marine engines, where occasionally they had hot bearings, and where there were much greater pressures used than had been spoken of. The system (Figs. 12 to 14, Plate 90, copied from a tracing kindly furnished to him by Mr. Rennie) was as follows. A brass ring or circular trough A was attached to the crank shaft, and when running quick it was evident that any oil dropped into it would *keep in* by centrifugal force alone; then a

branch B from this trough allowed the oil to run out in a radial direction by centrifugal force, to the crank-bearing C, which was bored up with a small hole D, having two branch holes EE, opening out into the bearing itself, where the connecting-rod took hold. Thus there was a full supply of oil from a fixed reservoir and pipe to the bearing itself. Mr. Rennie informed him that this plan, or something like it, had been used at Portsmouth Dockyard.

Mr. R. Price Williams said that one aspect of the question had exceedingly interested him as a railway man—namely the axle-friction of railway vehicles. He himself, and Mr. Webb, and many others, had for a long time held the opinion that the formulæ for train-resistance called Clark's formulæ, based upon experiments carried out thirty years ago, were in every way unreliable; and certainly the very important results attained by the present experiments seemed to confirm that view. Certain other important results at brake trials also lent countenance to the idea that the 8 lbs. per ton, with which they were so familiar as a constant for axle-friction, was entirely mythical. That pointed to the necessity of continuing the experiments in regard to tractive power and train-resistances. It was a very important matter; and if by any different arrangement of the axle, as had been pointed out in the paper, the frictional resistance could be lessened, the results at the present time ought to be very important indeed.

The author at page 640, had made this observation: "The fact that this arrangement of grooves, which is found to answer in the axles of railway vehicles, was found to be perfectly useless in this apparatus, can only be accounted for by the fact that a railway axle has a continual end-play while running, which prevents the brass from becoming the perfect oil-tight fit which it became in this apparatus." Then it was stated that "The attempts to make this arrangement of lubrication answer were not abandoned until after repeated trials." That remark appeared to him to point to the necessity of testing by actual experience whether those grooves, which were found not to answer under those conditions, really did answer in the case of railway axles. Apart from some proof that

they did answer, he was disposed to question the fact; and he should be glad if locomotive engineers would give their experience as to whether the plan did answer or not. The sooner the matter was gone into by them, he thought, the better it would be.

The PRESIDENT said it was exceedingly desirable to elicit as much information as possible from the members in regard to their experience as to friction; and he would therefore adjourn the discussion to the next meeting.

FIRST REPORT TO THE COUNCIL OF THE COMMITTEE ON FRICTION AT HIGH VELOCITIES.

(*First issued Nov.* 1879, *and now published by order of the Council.*)

Members of the Committee:—E. A. Cowper, Esq.; Capt. Douglas Galton, C.B., Hon. D.C.L., F.R.S.; Dr. John Hopkinson, F.R.S.; Prof. H. C. Fleeming Jenkin, F.R.S.; John Ramsbottom, Esq.; Lord Rayleigh, F.R.S.; Prof. A. B. W. Kennedy (*Reporter*).

The subject with which this Committee has to deal has been defined as "Friction at high velocities, specially with reference to friction of bearings and pivots, friction of brakes, &c." As the essential question involved in this is *the influence of velocity upon frictional resistance*, it has appeared neither necessary nor advisable that the Reporter should give any special account of what has been written upon the subject of friction generally. Unfortunately however the results of his examination of the numerous works and papers bearing upon the subject to which he has had access have been chiefly negative, so far as relates to the particular question in hand. Very little work appears to have been done in connection with this question; and even of what has been done much seems inapplicable—on account of difference of conditions—to the ordinary work of the mechanical engineer.

A difference has long been recognised between what has been called Static Friction, or the Friction of Rest, and Dynamic Friction, or the Friction of Motion, the coefficient in the former case being in many instances much higher than in the latter. The recent experiments of Professor Fleeming Jenkin in connection with this matter, although made at the opposite end of the scale of velocities

to that about which the Committee is now chiefly concerned, have great interest in connection with the general question of velocity and friction. By experimenting at extremely low velocities, he has shown * that in certain cases, where there is a very marked difference between the two coefficients mentioned, the coefficient of friction decreases gradually as the velocity increases, between speeds of 0·012 and 0·6 foot (0·0036 and 0·183 metre) per minute; and his experiments indicate a probability of a *continuous* rather than a *sudden* change in the value of the coefficient between the conditions of rest and motion. In cases where there is little or no difference between the coefficient of rest and motion, no difference was found at the velocities between which he experimented. His experiments were made with a very small steel spindle of 0·1 inch ($2\frac{1}{2}$ millimetres) diameter only, resting in rectangular V notches, the pressure being constant, and due to the weight (86 lbs. = 39 kg.) of a disc carried by the spindle, and revolving with it.

Professor A. S. Kimball has made a number of experiments † upon the question of velocity and friction. At common, but somewhat slow speeds, he finds the friction between pieces of pinewood to decrease rapidly as the speed increases. With a wrought-iron shaft of 1 inch (25 millimetres) diameter, working in a cast-iron bearing, well oiled, an increase of velocity of rubbing from 6 to 110 ft. (1·8 to 33·5 metres) per minute caused the coefficient of friction to fall to 0·3 of its first value. The pressure in this case was about 67 lbs. per sq. in. (4·7 kg. per sq. centimetre). Other experiments on lubricated journals at smaller pressures gave a diminution of the coefficient from 0·15 to 0·05, as the velocities increased from 1 to 100 ft. (0·3 to 30 metres) per minute. At such slow speeds as from 0·59 to 2·2 ft. (0·18 to 0·67 metre) per minute a similar decrease was found; while at the still lower velocities of from 0·002 to 0·01 ft. (0·0006 to 0·003 metre) per minute the friction *increased* with the velocity.

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* Royal Society, Proceedings, 1877, p. 93.

† 'American Journal of Science,' 1876 and 1878; also Thurston's 'Friction and Lubrication,' p. 182, *et seq.*

Professor R. H. Thurston has carried out a number of experiments to determine the effect of changes, not only in velocity but also in pressure and in temperature, upon the frictional resistance in lubricated bearings.* His conclusions are that the coefficient at first decreases, but after a certain point *increases* with the velocity, the point of change varying with the pressure and the temperature. At a pressure, for instance, of 100 lbs. per sq. in. (7 kg. per sq. centimetre) and a temperature of 150° F. (65° C.), the minimum value of the coefficient is reached at a speed lying between 100 and 250 ft. (30 and 75 metres) per minute; while at the same pressure, but at a much lower temperature (apparently), the value of the coefficient *increases* continuously from 30 ft. (9 metres) per minute, the lowest velocity tried, up to 1200 ft. (360 metres) per minute. As the general result of his work, Professor Thurston has come to the conclusion that for a cool and well lubricated bearing the coefficient of friction *increases* with the velocity, and approximately as its fifth root, at all speeds exceeding 100 ft. (30 metres) per minute. It is much to be regretted that Professor Thurston has published no information about his very important experiments, in this part of the subject, except a few Tables of epitomised results. Neither the sizes of the journals tested, the number of tests made, nor any particulars as to the variation of the experiments among themselves are given, and very few details as to the way in which they were carried out. Until this information is made accessible (as it is to be hoped it will be made) it is not easy to estimate the degree of importance to be attached to these results.

The well known experiments of Poirée and Bochet † show that between velocities of 900 and 3600 feet (270 and 1080 metres) per minute the coefficient of friction both of wheels and of shoe brakes skidding on rails diminished very much—approximately (in the former case) from 0·2 to 0·13. The surfaces were of course quite unlubricated.

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* 'Friction and Lubrication,' p. 185. American Association for Advancement of Science, Aug. 1878, p. 61.

† Mem. de la Soc. des Ing. Civ. 1852, p. 110, &c. Comptes Rendus, xlvi. (1858), p. 802, and li. (1860), p. 974.

The recent experiments of Captain Douglas Galton and Mr. Westinghouse, described by Capt. Galton in his papers read before the Institution,* afford very valuable information as to the effect of change of velocity upon the frictional resistances between brake-blocks and wheels, and also as to the simultaneous variation of the coefficient of friction with the *intensity* of pressure, or pressure per unit of area. These experiments throughout showed a very remarkable diminution of the coefficient of friction with increase of speed over the very large range of from 400 to 5300 feet (120 to 1600 metres) per minute. The nature of the appliances used however permitted observations to be made only for about 30 seconds consecutively; and it was found that during this time the coefficient of friction always diminished rapidly. This decrease must of course cease after some time,—apparently after a very short time,—and the question arises, as was suggested by the Reporter in the discussion on one of Captain Galton's papers, whether the difference between the frictional resistances at different speeds would still remain when these resistances had taken up their lowest values, or would then have disappeared. So far as can be judged from plotting out Captain Galton's results,† the difference would remain. From working out a number of these brake experiments, the Reporter found that the coefficient of friction was sensibly *less* at higher than at lower pressures, and that the coefficient of friction between the wheels and the rails (where the intensity of pressure might easily be seventy or eighty times as great as on the brake blocks) was less than a third of that between the wheels and the brakes. From Professor Thurston's experiments with journals there appears the notable result that, while this is substantially corroborated for ordinary velocities and loads, there comes always a point (varying irregularly in the different cases and with different lubricants), after which increase of pressure *increases* the coefficient of friction, this change being more marked in the case of the lower velocities. The particular point at which this change occurs seems also to be partly dependent

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* See Proceedings Inst. M. E., June and October 1878, and April 1879.

† Proceedings Inst. M. E., April 1879, Pl. 23, Fig. 14.

on the temperature. Within ordinary limits Professor Thurston takes the friction to vary (*ceteris paribus*) inversely as the square root of the pressure per unit of area; but this conclusion is very far from representing the average results of those sets of experiments which he has selected for publication.

No very large number of answers have been received to the enquiries sent out upon this subject. Of those which have come in, the most interesting are (1) a letter from Mr. Pearce of Cyfarthfa, and (2) a letter from General Morin. The former gives particulars of indicator tests of a rolling-mill engine running empty at different speeds, from which it appears that proportionately a much smaller power was required to drive the engine at a high than at a low speed. The experiments are not of such a nature as to allow any general conclusions to be drawn from them; but they have considerable intrinsic interest, as relating to a form of experiment easily made, and the results of which, noted in a sufficient variety of cases, would afford really valuable information. General Morin's letter is specially interesting, as coming from such a veteran worker in the subject of friction as its writer. He disclaims altogether any notion that from his original experiments laws of friction could be laid down for conditions outside those under which he worked; and sees no reason to doubt that under such high velocities as often occur in practice the coefficient of friction may be considerably reduced. He thinks that an apparatus somewhat similar to that which he used, but modified in detail, would probably be the most convenient for carrying out further experiments. General Morin's letter is appended to this report.

The chief experiments made directly in connection with the subject under the consideration of the Committee have now been cited. From them it may be taken as established that, even at quite ordinary speeds, the value of the coefficient of friction between different varieties of iron or steel is sensibly changed by changes in the velocity of rubbing. For dry rubbing surfaces there can be little doubt that this change is a continuous decrease as the velocity increases up to the limits of the experiments made; for lubricated surfaces, of the form of ordinary bearings (having however pressure

on *both* sides of the journal), Thurston's experiments point to the conclusion that at some point the coefficient ceases to decrease with increasing velocity, and begins to increase again. This conclusion can hardly be accepted as final without confirmation. It has as yet been found only by one experimenter, and his results are in many points anything but regular. But at the same time no other experiments have apparently been made with lubricated bearings at anything like the speed (1200 ft. or 360 metres per minute) up to which he has worked.

Besides the general conclusions that the coefficient of friction is greatly affected by the velocity of rubbing, the existing experiments also show that it is greatly affected by the intensity of bearing pressure; and they raise some probability that the effect of altering the pressure is different at different speeds. It will hardly be possible therefore, in carrying out any experiments which may be thought advisable upon this subject, to dissociate the question of varying pressure from that of varying velocity. In working with lubricants it is also clear that the temperature very much affects the coefficient of friction; but there is very little evidence as to the effect of ordinary changes of temperature upon dry bearings.

ALEX. B. W. KENNEDY,
Reporter.

APPENDIX.

[*Translation.*]

Conservatoire des Arts et Métiers,
Paris, 15th March, 1879.

Dear Sir,—

The results furnished by my experiments as to the relations between pressure, surface, and speed, on the one hand, and sliding friction on the other, have always been regarded by myself, not as mathematical laws, but as close approximations to the truth within the limits of the data of the experiments themselves. The same holds, in my opinion, for many other laws of practical mechanics: such as those of rolling resistance, fluid resistance, &c.

It has therefore been no surprise to me that, in experiments on the resistance to the sliding of skidded railway wheels over rails, this resistance has appeared to diminish at higher speeds. The vibrations and strains produced in such cases would moreover occasion disturbances such as would wholly change the results.

For journals revolving in stationary bearings, it is natural that, as the efficiency of the lubrication is affected by the speed, the friction should be so also.

In the case therefore of loads, surfaces, or speeds, which largely exceed the limits of those that have formed the subject of my own investigations, I agree with the Institution of Mechanical Engineers that it would be well for further experiments to be tried.

But after mature consideration I am of opinion that the question might be solved by an apparatus of a kind similar to the one I made use of, as described (page 13, *et seq.*) in the Paper published in 1838 by the Academy of Science: provided that the new experiments were tried on a larger scale in regard to weight, diameter, and speed.

In the apparatus referred to, the rotary dynamometer, which was the first of its kind, was mounted direct on the axle that was being experimented upon. It would be better that it should be separate from it, and that the axle should be driven by a belt.

The kind of rotary dynamometer that I have subsequently employed, of which there are several models in the Conservatoire, is very convenient for these experiments, and can be used for high speeds. It would afford greater facility for applying sufficiently heavy loads.

The diameter of the bearings should be much greater than is required for strength, in order that a sufficiently high surface velocity may be obtained with a moderate speed of revolution.

For experiments made without any lubrication, anomalous results arising from wear produced by long-continued friction of the same surfaces might be avoided, if instead of fixed bearings an annular bush surrounding the journal were employed, which by some easily contrived arrangement might be shifted circumferentially at pleasure, either with a continuous movement or at intervals.

The above are the suggestions that at present occur to me to offer in regard to arranging further experiments on the friction of axles in their bearings.

If any scheme for an experimental apparatus in accordance with these ideas be submitted to me by the Institution, I shall have much pleasure in examining it and giving my opinion upon the arrangements proposed.

I am, Dear Sir,

Yours very truly,

GENERAL A. MORIN.

WALTER R. BROWNE, Esq., *Secretary*,
Institution of Mechanical Engineers, London.

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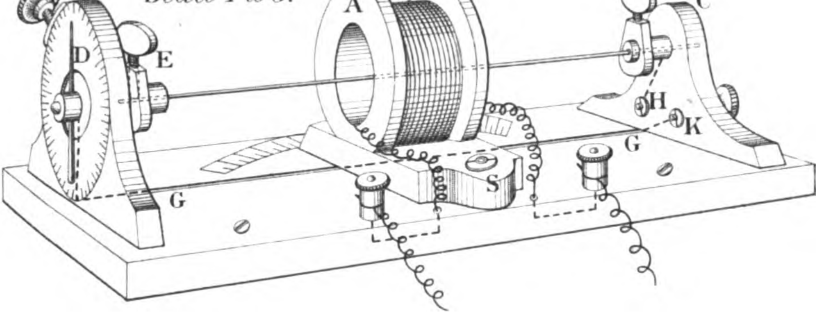
Fig. 1. *Sketch of Apparatus.*

Scale 1 to 3.



Position of Molecules, Iron.

Fig. 2.

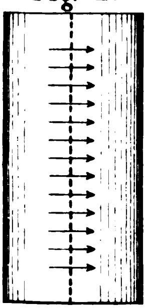


Fig. 3.

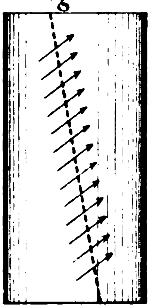


Fig. 4.

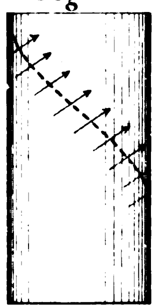


Fig. 5.

Position of Molecules, Steel.

Fig. 6.

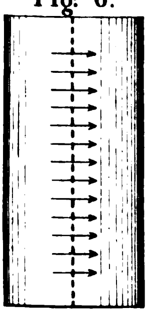


Fig. 7.

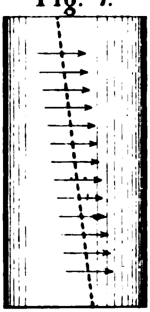


Fig. 8.

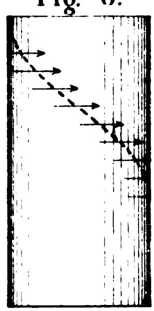
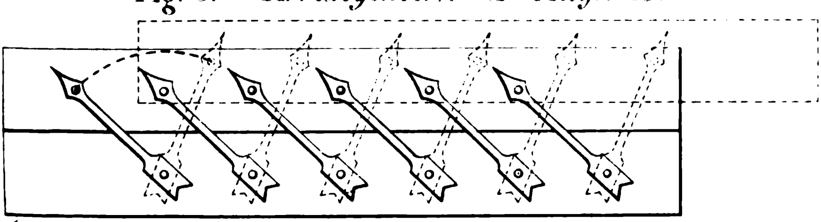


Fig. 9. *Arrangement of Magnets.*



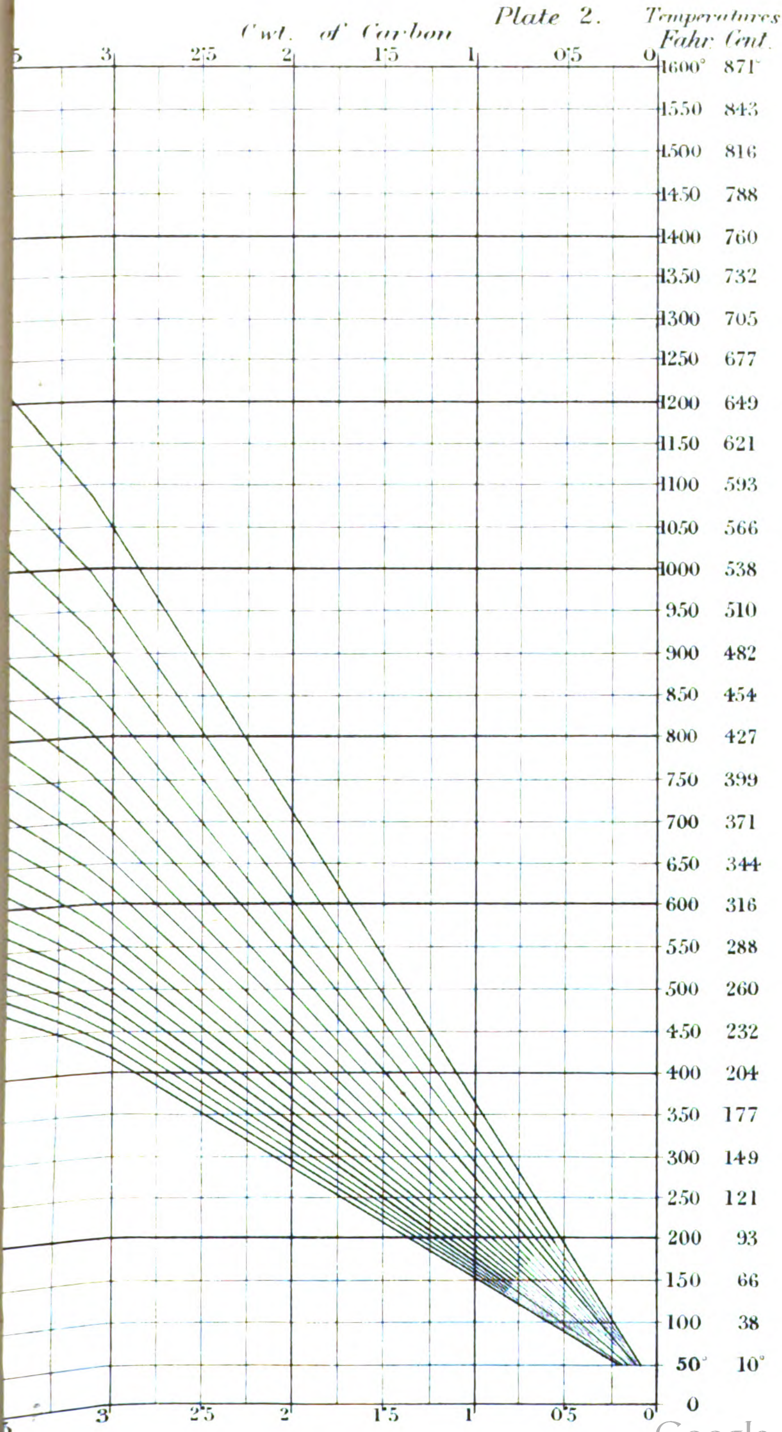
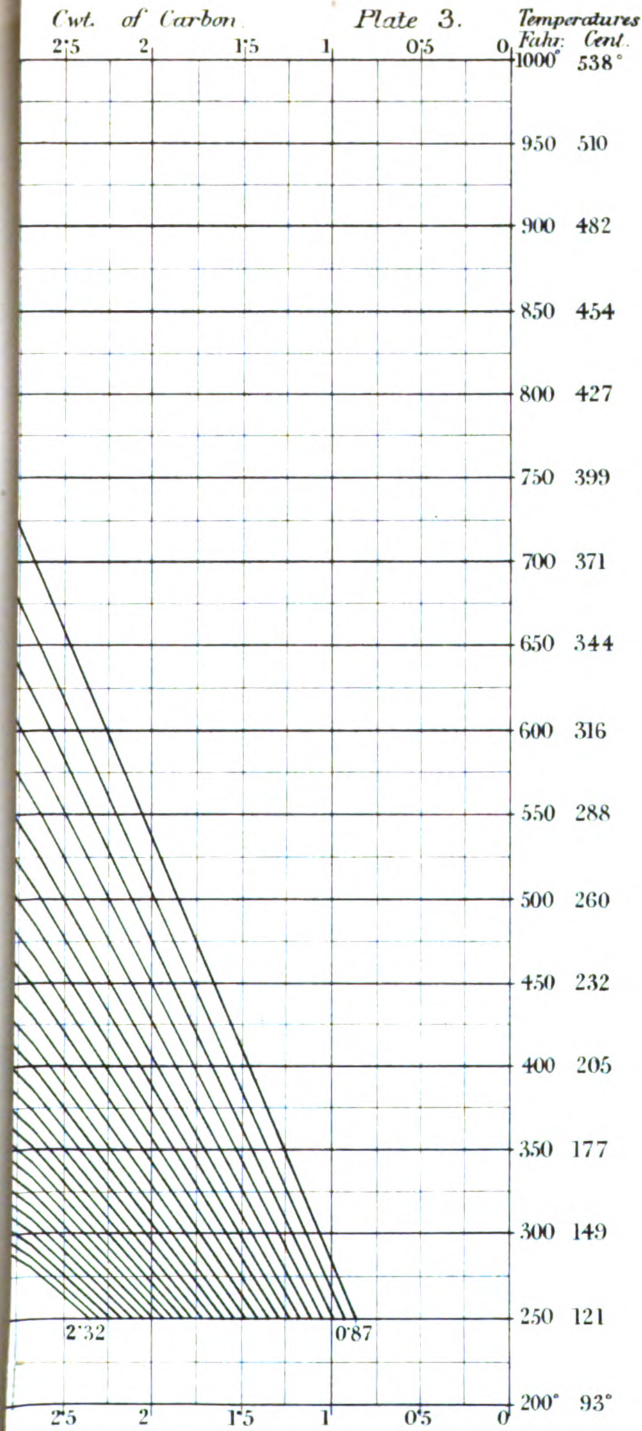
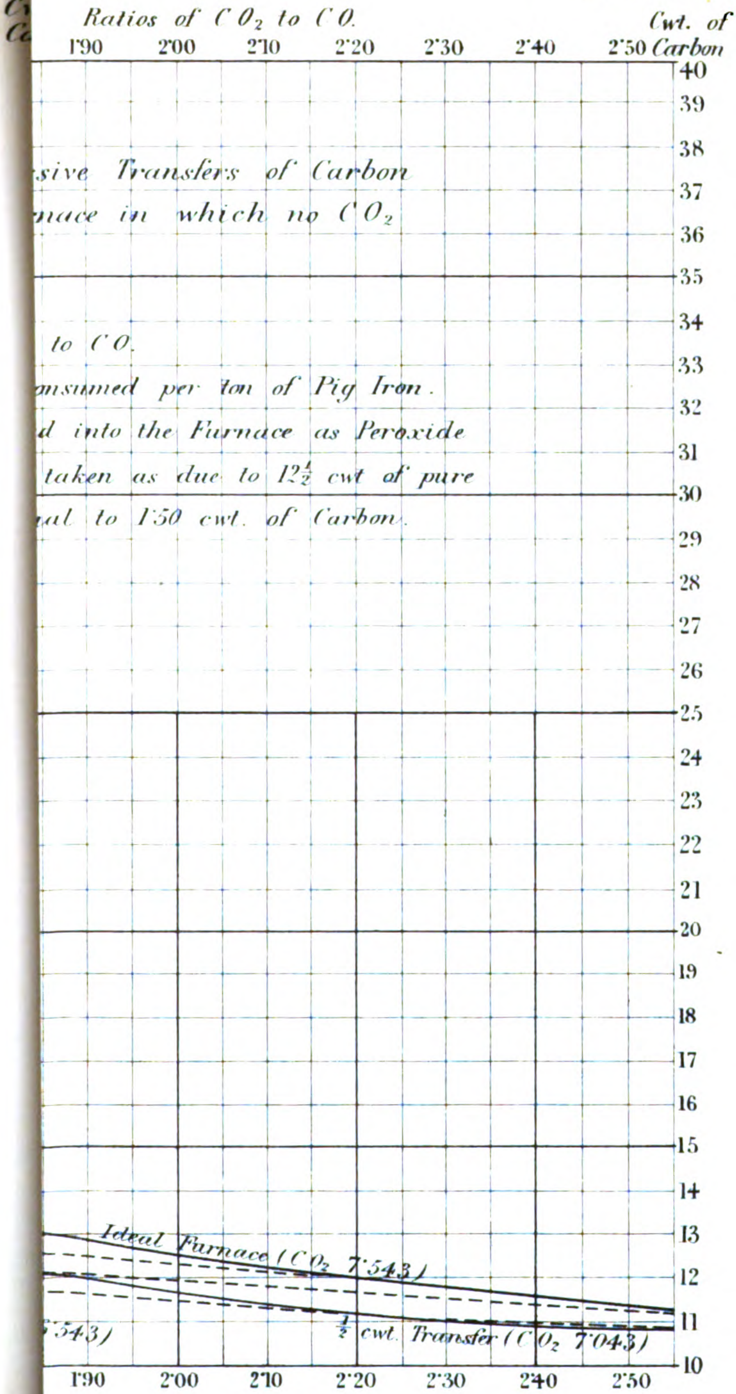


Plate 2.
Cwt. of Carbon
Temperatures
Fahr. Cent.
3
2·5
2
1·5
1
0·5
0
1600° 871°
1550 843
1500 816
1450 788
1400 760
1350 732
1300 705
1250 677
1200 649
1150 621
1100 593
1050 566
1000 538
950 510
900 482
850 454
800 427
750 399
700 371
650 344
600 316
550 288
500 260
450 232
400 204
350 177
300 149
250 121
200 93
150 66
100 38
50° 10°
0

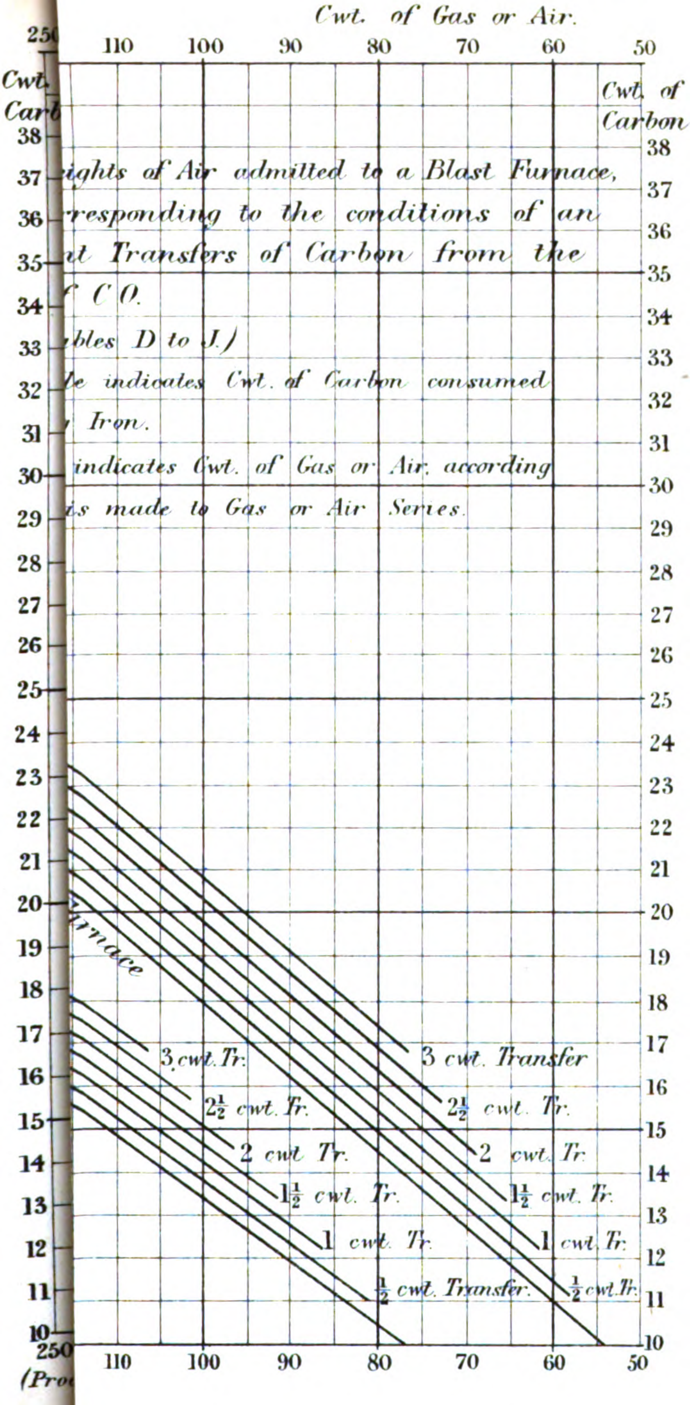


Cwt. of Carbon
Plate 3.
Temperatures
Fahr. Cent.
2·5 2 1·5 1 0·5 0
1000° 538°
950 510
900 482
850 454
800 427
750 399
700 371
650 344
600 316
550 288
500 260
450 232
400 205
350 177
300 149
250 121
200° 93°
2·32
0·87

Plate 4.

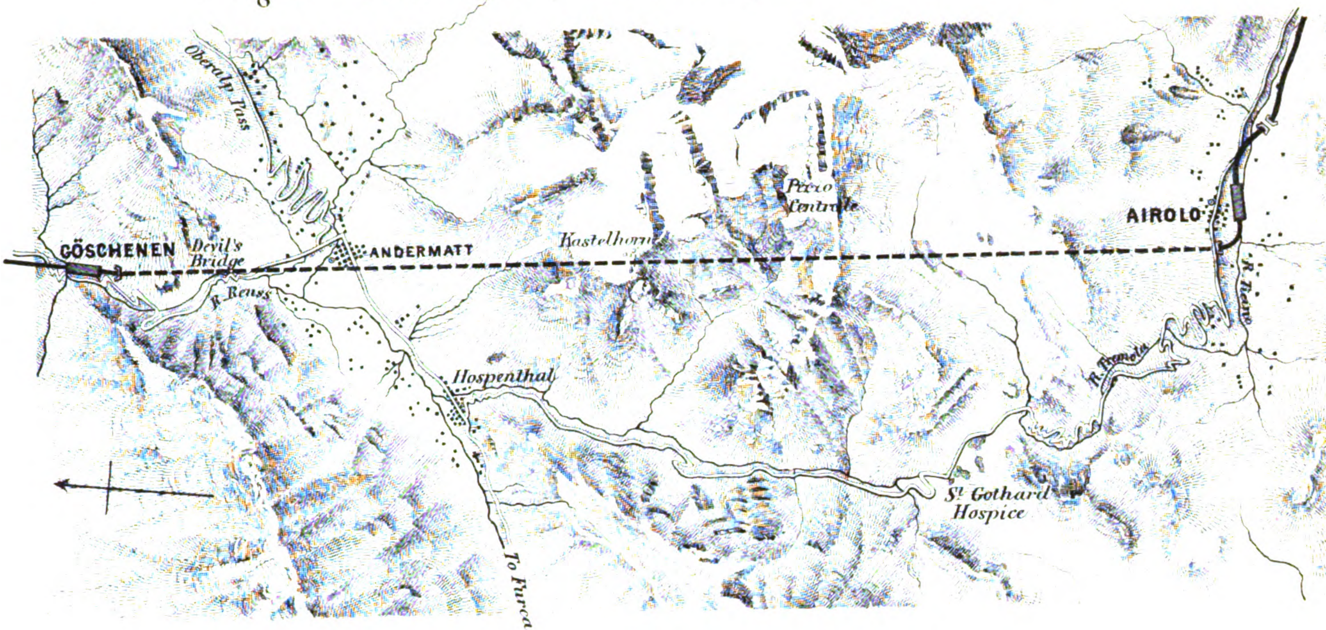


Ratios of CO_2 to CO.
Cwt. of Carbon
1·90
2·00
2·10
2·20
2·30
2·40
2·50
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
sive Transfers of Carbon
nace in which no CO_2
to CO.
nsumed per ton of Pig Iron.
d into the Furnace as Peroxide
taken as due to $12\frac{1}{2}$ cwt of pure
al to 1·50 cwt. of Carbon.
Ideal Furnace (CO_2 7·543)
·543)
$\frac{1}{2}$ cwt. Transfer (CO_2 7·043)


Cwt. of Gas or Air.
Cwt. of Carbon
ights of Air admitted to a Blast Furnace,
responding to the conditions of an
t Transfers of Carbon from the
f C O.
bles D to J.)
le indicates Cwt. of Carbon consumed
Iron.
indicates Cwt. of Gas or Air, according
is made to Gas or Air Series.
rnace
3 cwt. Transfer
3 cwt. Tr.
$2\frac{1}{2}$ cwt. Tr.
2 cwt. Tr.
$1\frac{1}{2}$ cwt. Tr.
1 cwt. Tr.
$\frac{1}{2}$ cwt. Transfer.
$\frac{1}{2}$ cwt. Tr.
(Pro

St GOTHARD TUNNEL.

Fig. 1. *Plan of the St Gothard pass, with line of Tunnel.*



Scale 1 to 100,000.

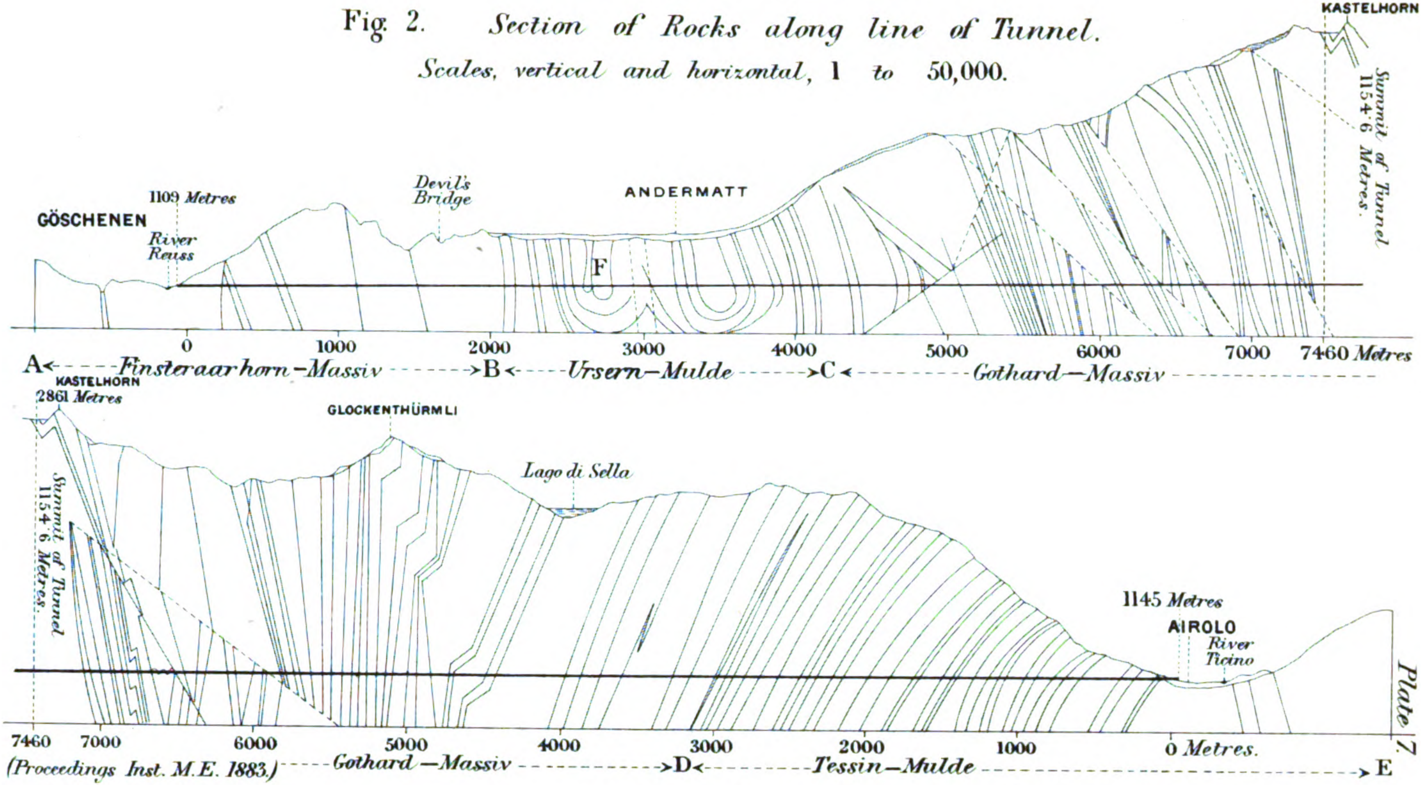
Plate 6.

(Proceedings Inst. M. E. 1883.)

S^T GOTHARD TUNNEL.

Fig. 2. *Section of Rocks along line of Tunnel.*

Scales, vertical and horizontal, 1 to 50,000.



(Proceedings Inst. M.E. 1883.)

ST GOTHARD TUNNEL.

Fig. 3. *Section showing mode of driving. Scale 1 to 200.*

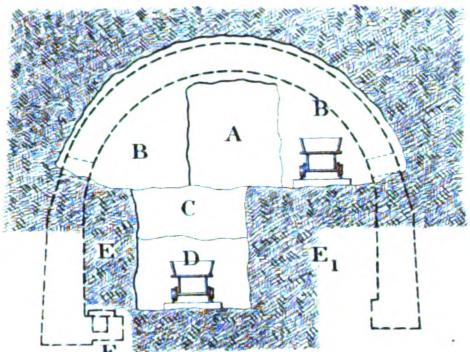


Fig. 5. *Elevation of Turbine and Gearing, Airolo. Scale 1 to 60.*

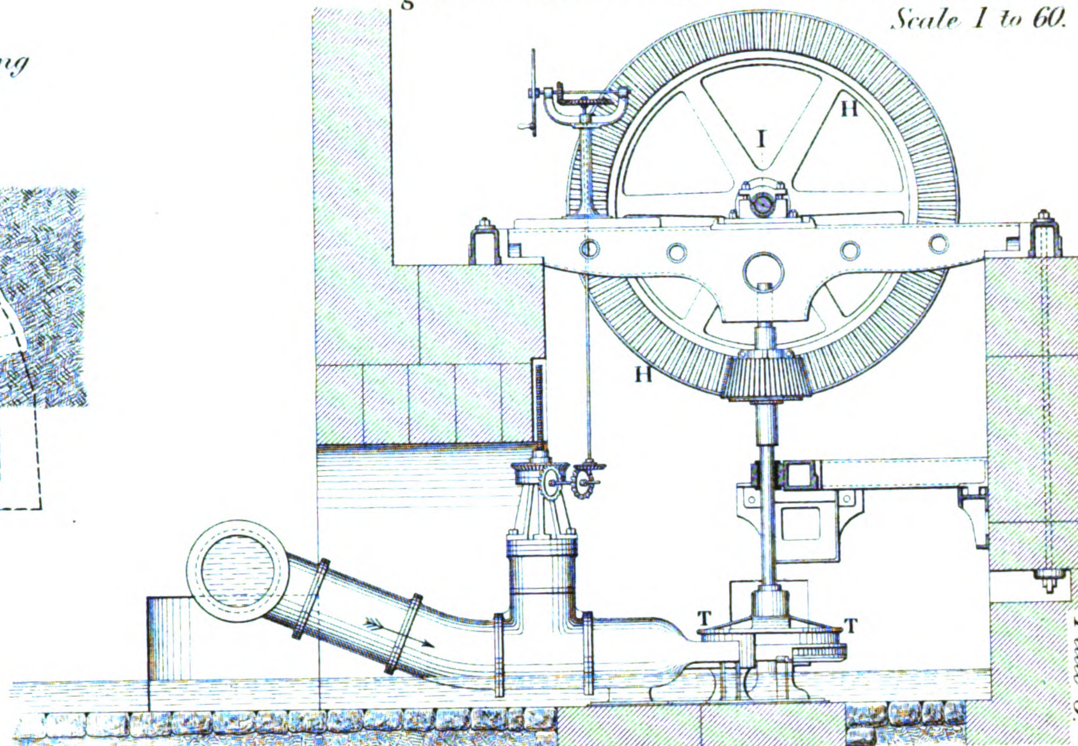
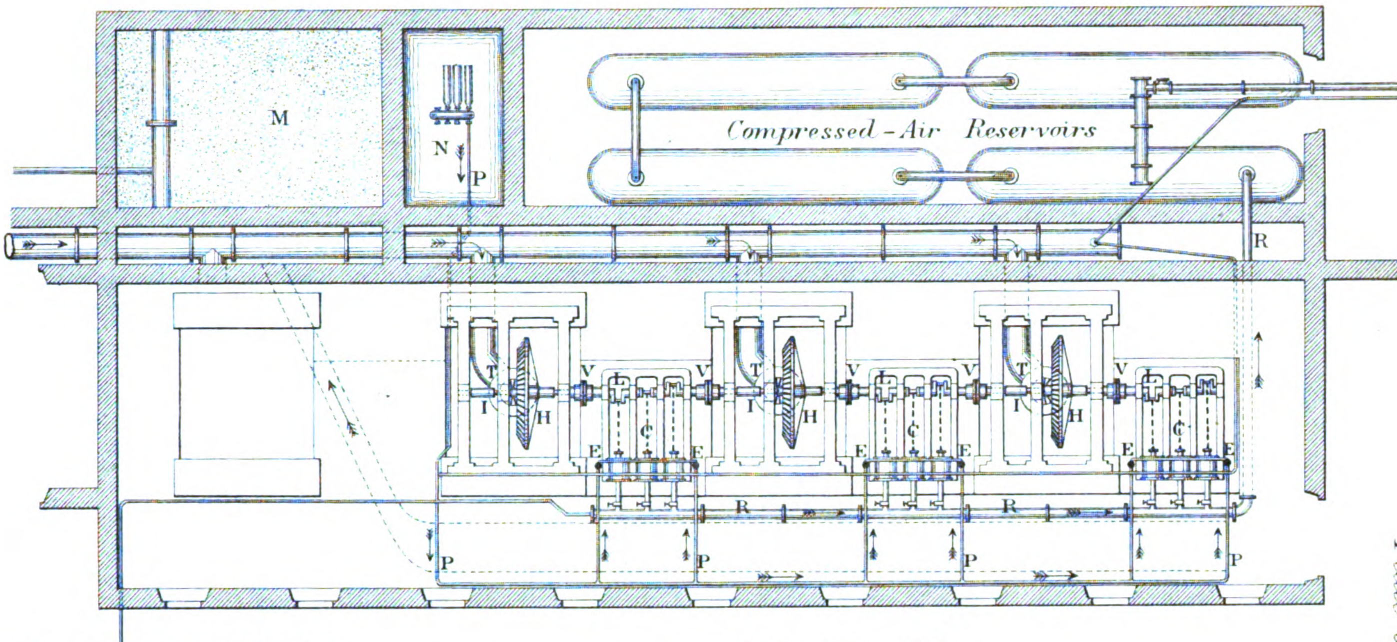


Plate 8.

(Proceedings Inst. M. E. 1883.)

S^T GOTHARD TUNNEL.

Fig. 4. *Plan of Turbine Shop, Airolo.*

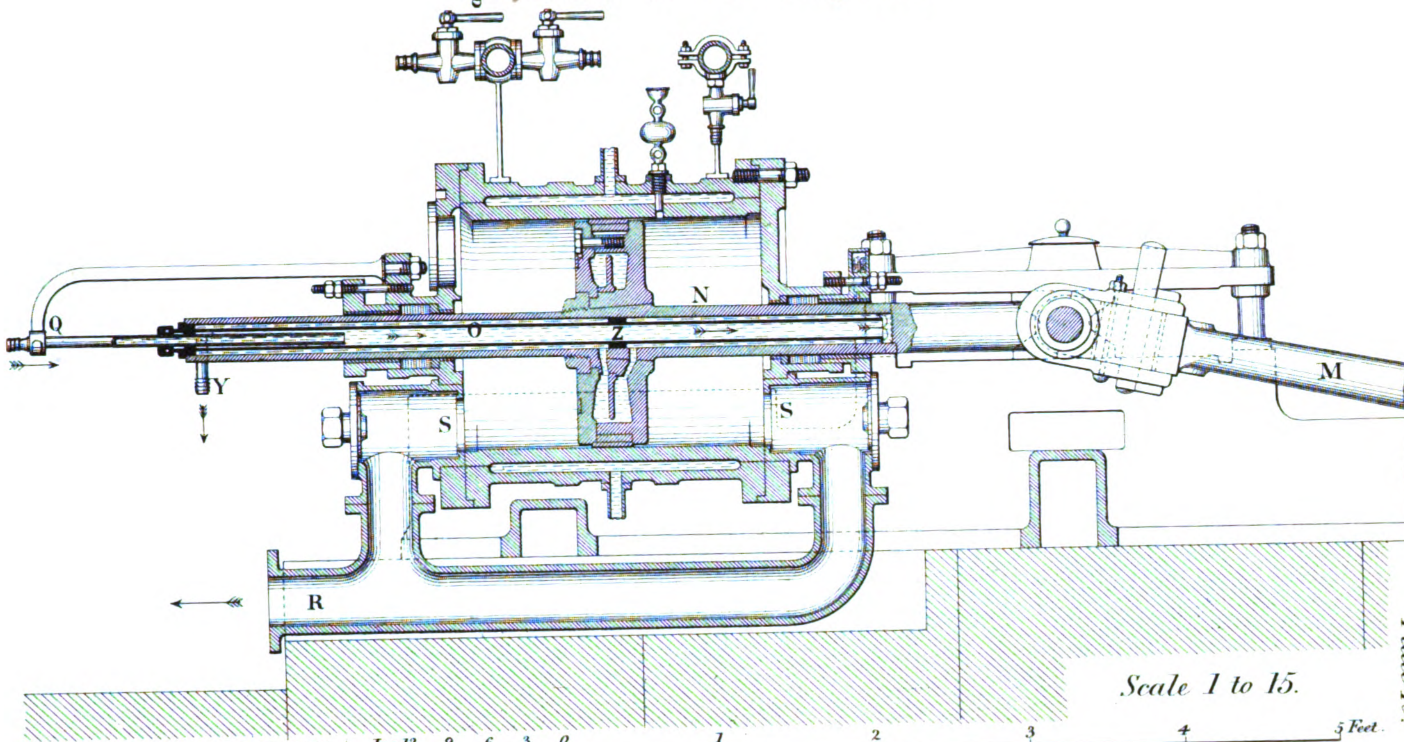


Scale 1 to 200.

Plate 9.

St. GOTHARD TUNNEL.

Fig. 6. *Section of Air-Compressor*



(Proceedings Inst. M. E 1883.)

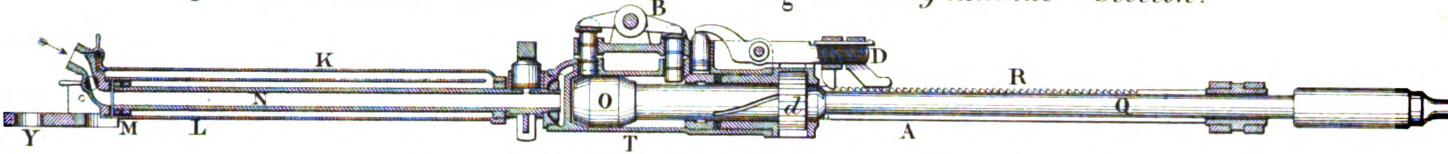
Plate 10.

S^T GOTHARD TUNNEL.

Plate 11.

Improved Ferroux Drill.

Fig. 7. Longitudinal Section.



Scale 1 to 15.

Fig. 8. Plan.

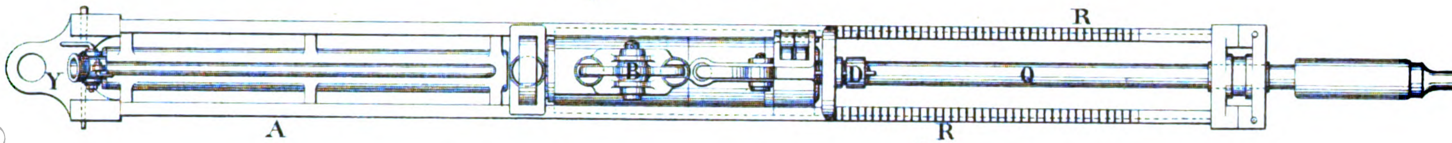


Fig. 9. Rear End.

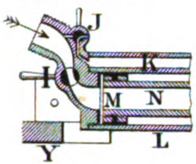


Fig. 10. Striking Cylinder.

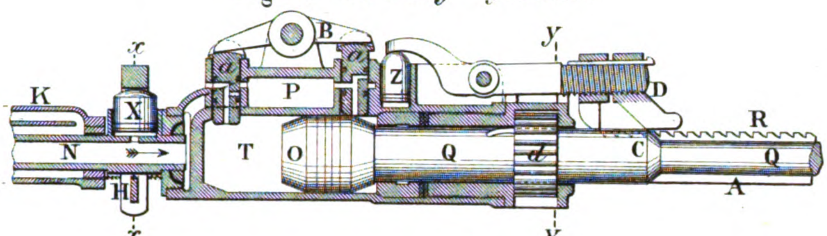


Fig. 11. Section at x x.

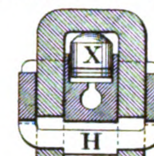


Fig. 12. Section at y y.

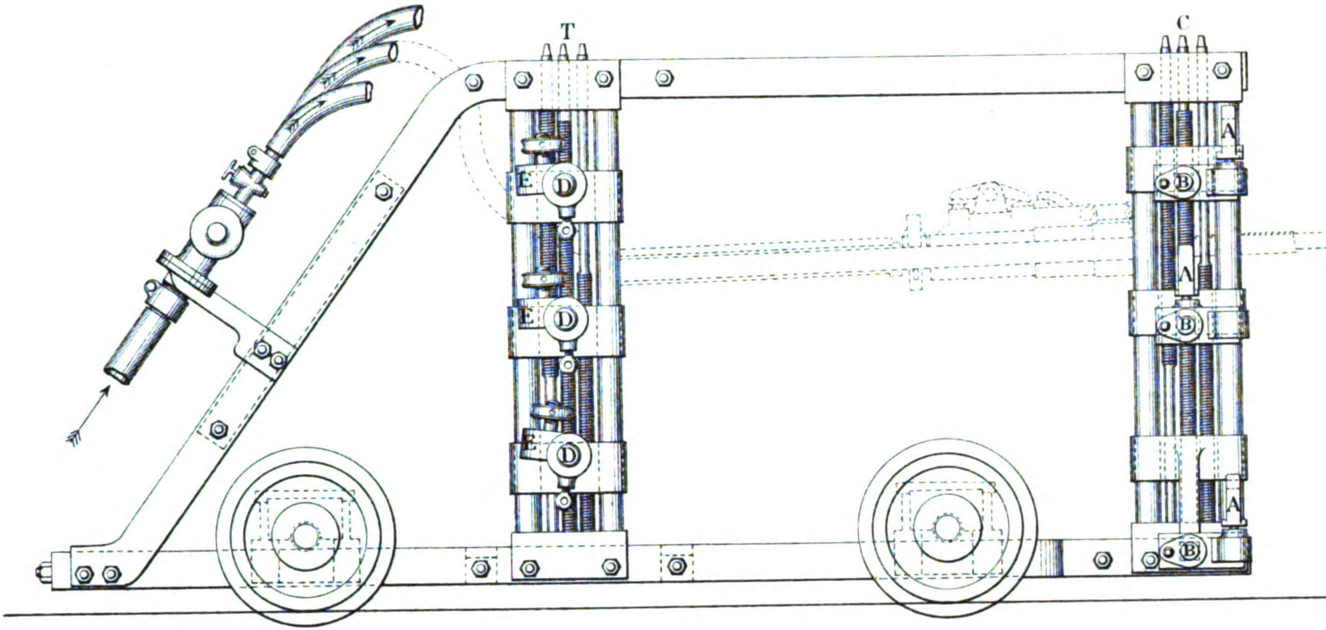
Figs. 9 to 12. Scale 1 to 10.

(Proceedings Inst. M.E. 1883.)

Plate 11.

ST GOTHARD TUNNEL.

Fig. 13. *Elevation of Drill-Carriage.*



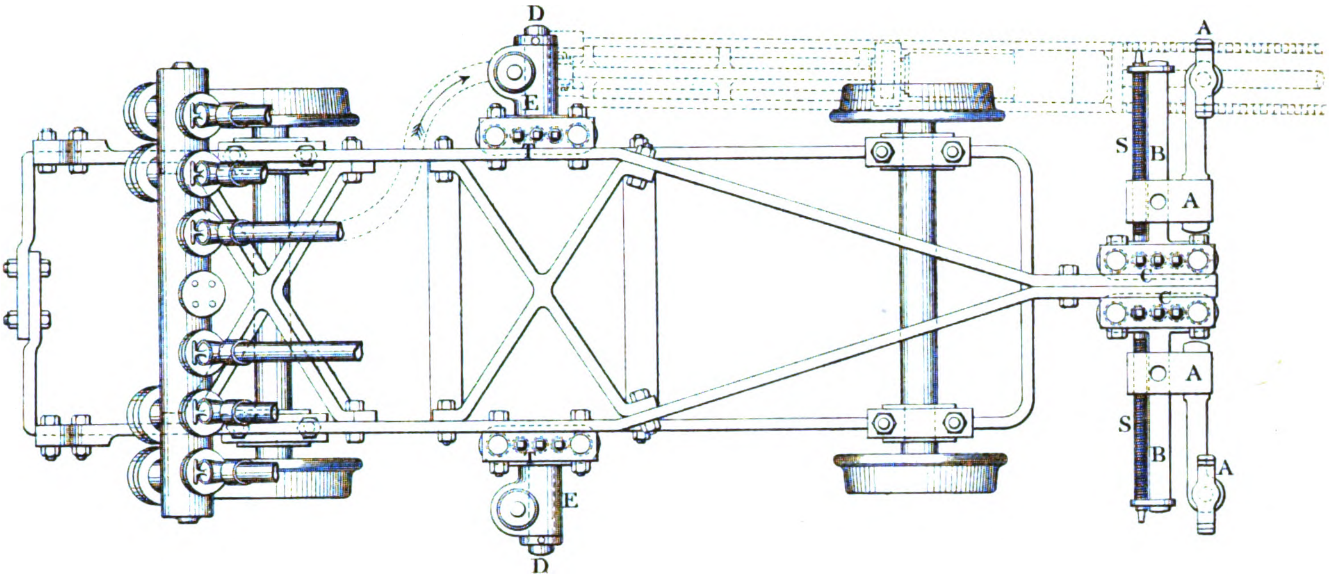
Scale 1 to 20.

(Proceedings Inst. M. E. 1883.)

Plate 12.

S^t GOTHARD TUNNEL.

Fig. 14. *Plan of Drill-Carriage.*



(Proceedings Inst. M. E. 1883.)

Scale 1 to 20.

Plate 13.

S^T GOTHARD TUNNEL.

Fig. 15. *Half Elevation of Drill Carriage.* *Scale 1 to 16.*

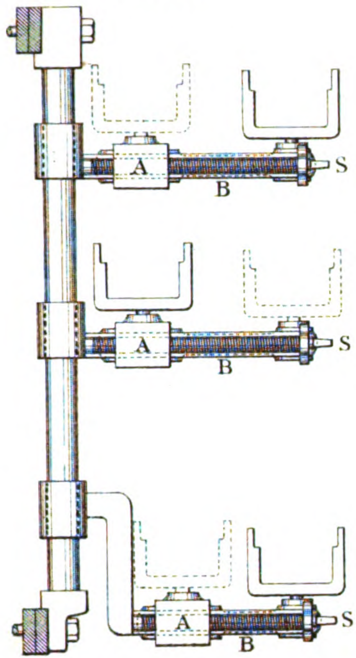
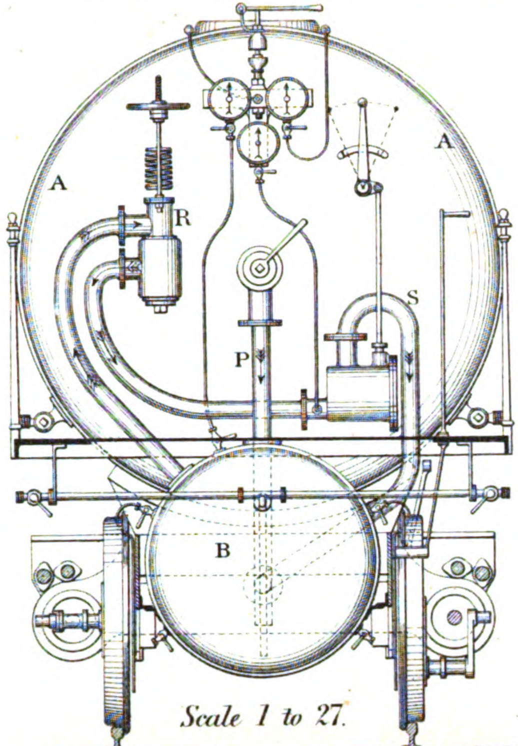


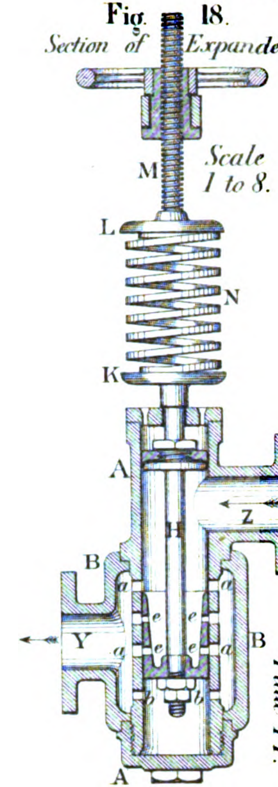
Fig. 17. *End Elevation of Air Locomotive.*



Scale 1 to 27.

Fig. 18. *Section of Expander.*

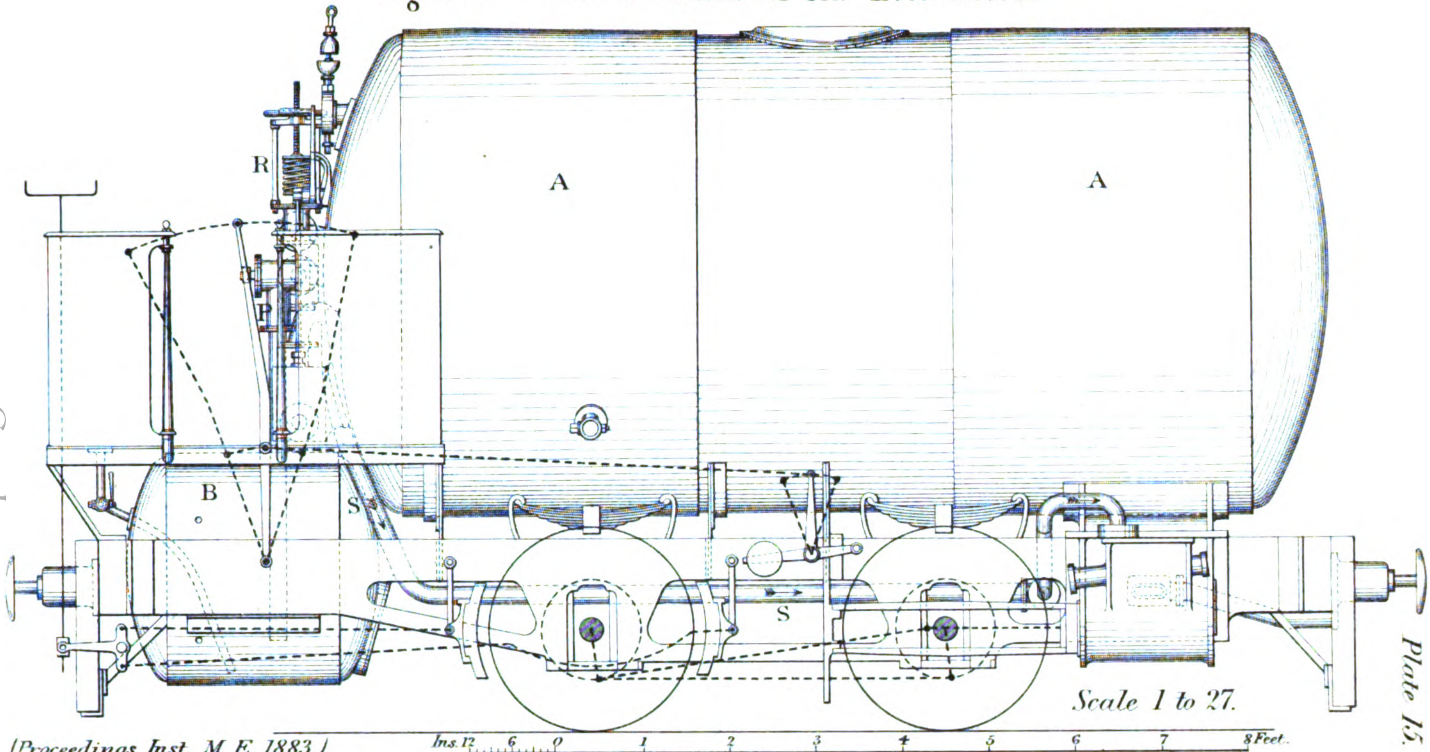
Scale 1 to 8.



(Proceedings Inst. M. E. 1883.)

St. GOTHARD TUNNEL.

Fig. 16. *Side Elevation of Air Locomotive.*



(Proceedings Inst. M.E. 1883.)

Plate 15.

STRENGTH OF SHAFTING.

Fig. 1. Screw-shaft, S. S. "Dorset."

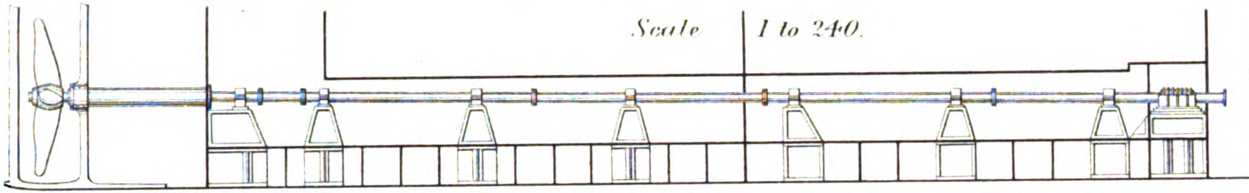


Fig. 2. Section of Shaft, "City of Rome."

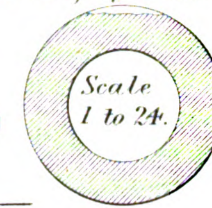
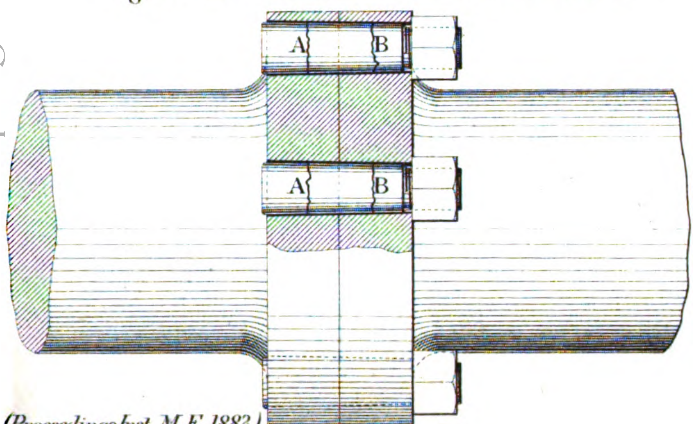


Fig. 13. Broken Bolts in Screw-shaft.



Experiments on Hollow and Solid Shafts.

Fig. 15.

Fig. 16.

Fig. 14.

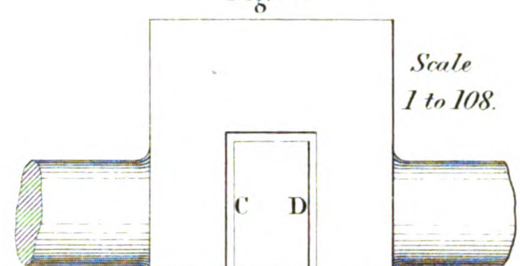


Plate 16.

STRENGTH OF SHAFTING.

Fig. 3.

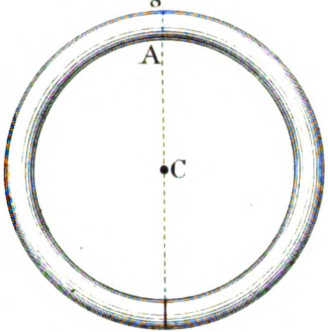


Fig. 4.

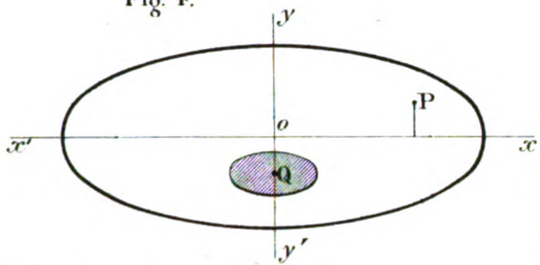


Fig. 5.

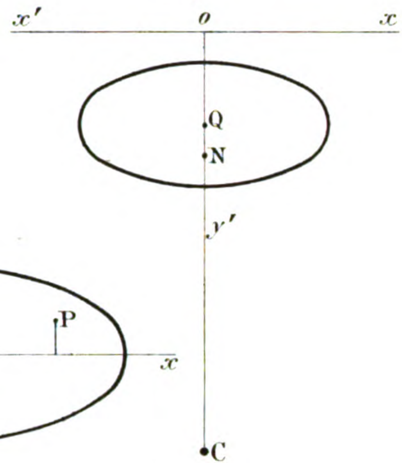


Fig. 6.

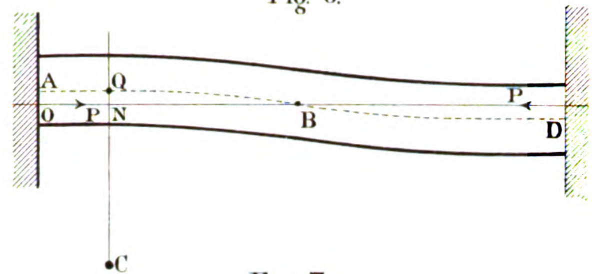


Fig. 7.

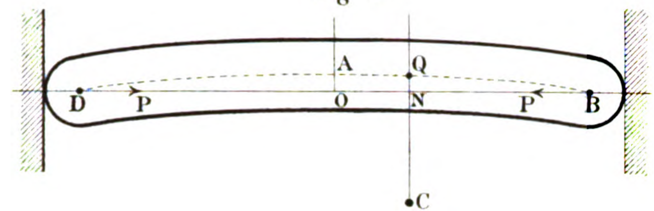
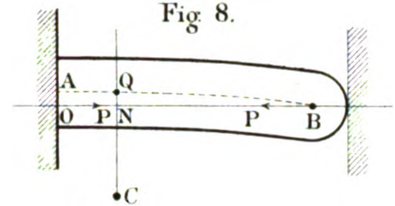


Fig. 8.



(Proceedings Inst. M. E. 1883.)

Plate 17.

STRENGTH OF SHAFTING.

Fig. 9.

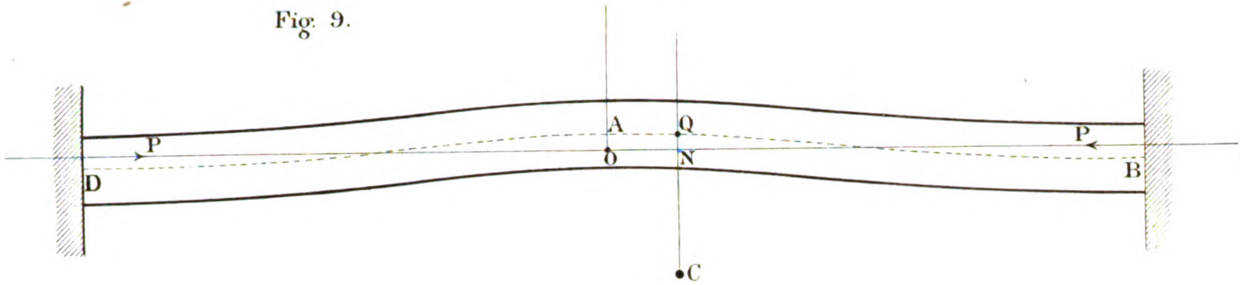


Fig. 10.

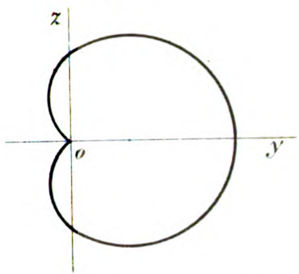


Fig. 11.

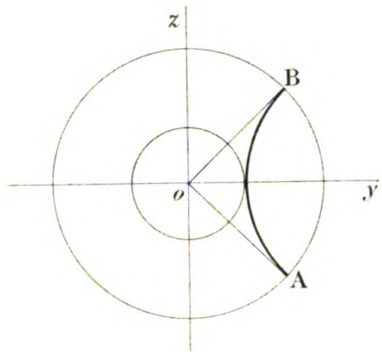


Fig. 12.

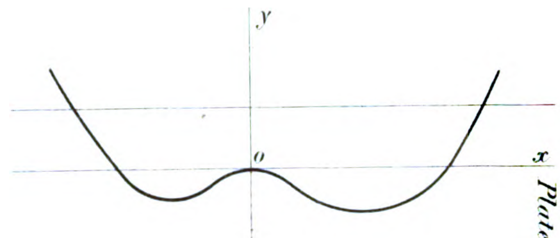


Plate 18.

CUTTING OF METALS.

Plate 19.

Swivel Tool-holders.

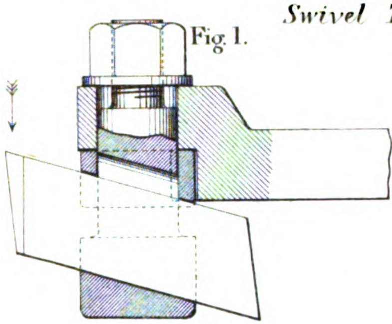


Fig. 1.

Fig. 4.

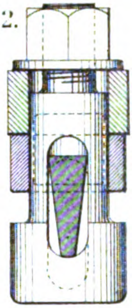


Fig. 2.

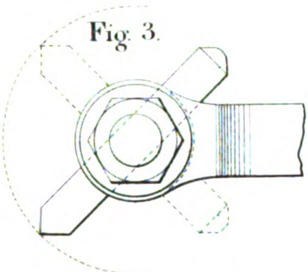


Fig. 3.

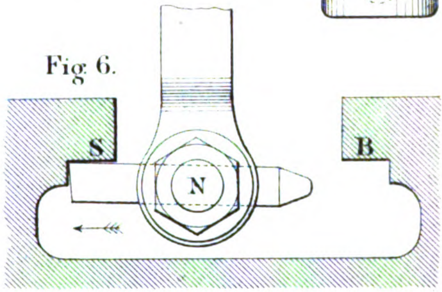


Fig. 6.

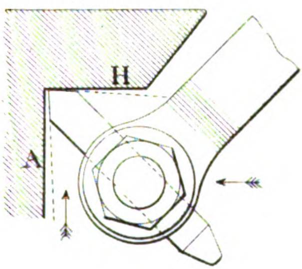


Fig. 5.

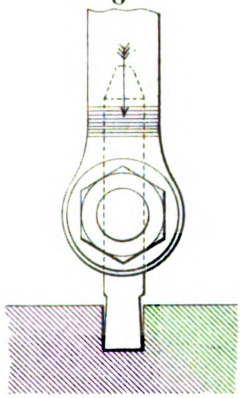


Fig. 8.

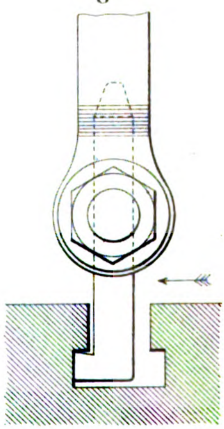


Fig. 10.

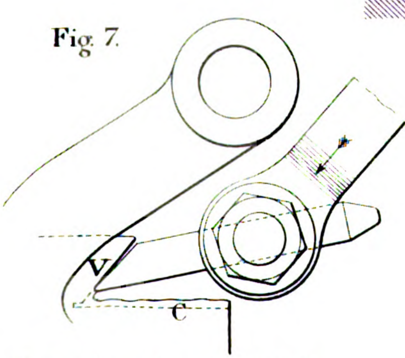


Fig. 7.

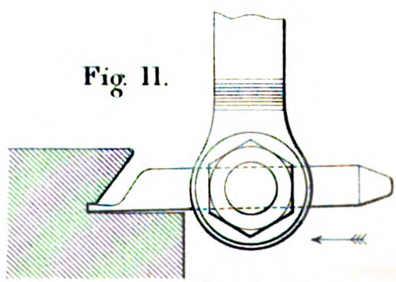


Fig. 11.

(Proceedings Inst. M.E. 1883.)

Scale 1 to 3.

Tool-holder for Planing Machines.

Fig. 9A.
Scale 1 to 8.

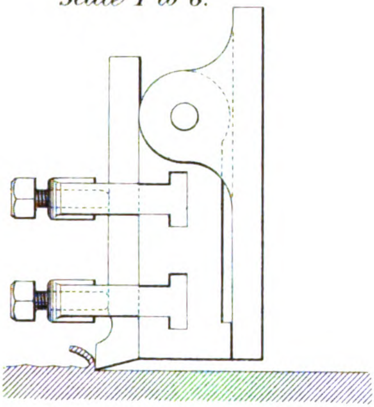
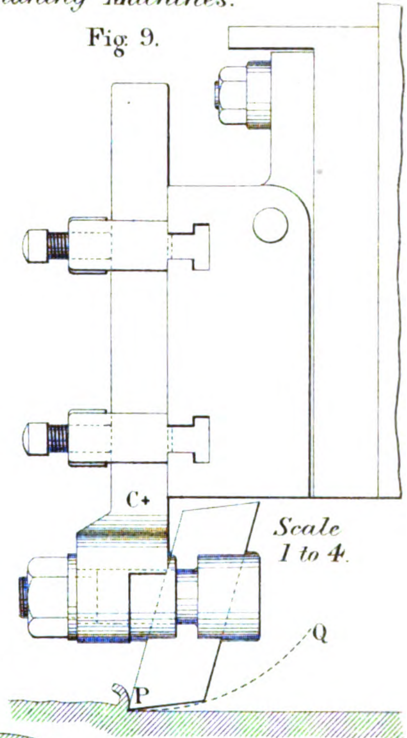


Fig. 9.



Scale 1 to 4.

Fig. 9B.
Scale 1 to 8.

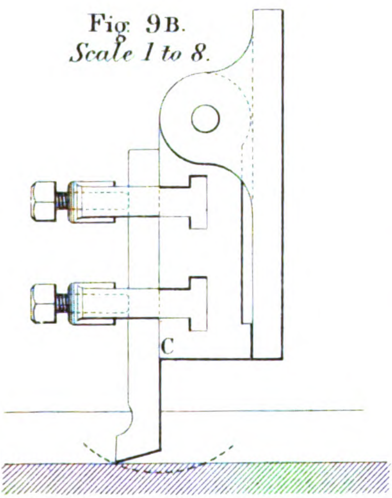
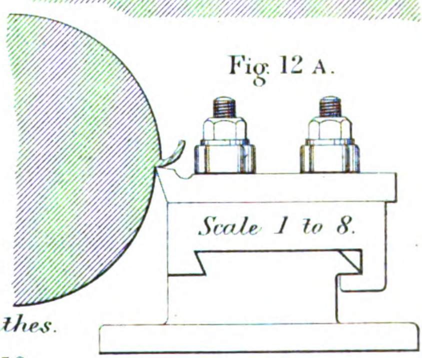


Fig. 12 A.



Scale 1 to 8.

Tool-holder for Screw-cutting Lathes.

Fig. 12.

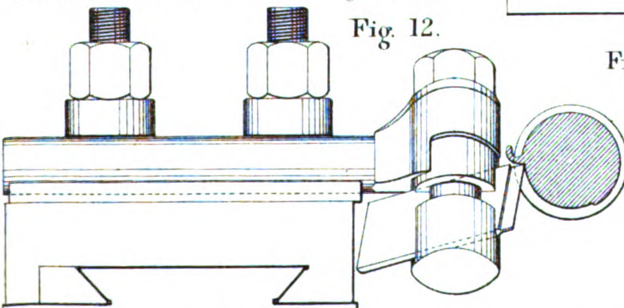
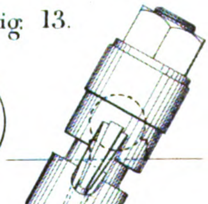


Fig. 13.



(Proceedings Inst. M. E. 1883.)

Scale 1 to 4.

Ending Tool-holder.

Fig. 15.

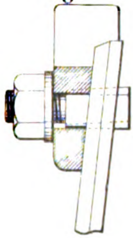


Fig. 14.

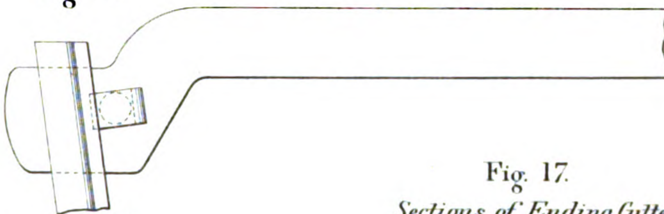


Fig. 16.

Scale 1 to 4.

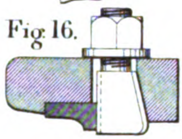


Fig. 17.

Sections of Ending Cutters.

Scale 1 to 2.

Parting Tool-holder.

Fig. 19.

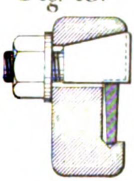


Fig. 18.

Fig. 20.

Scale 1 to 4.

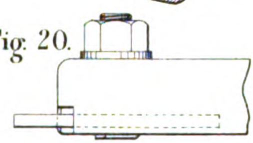


Fig. 21.

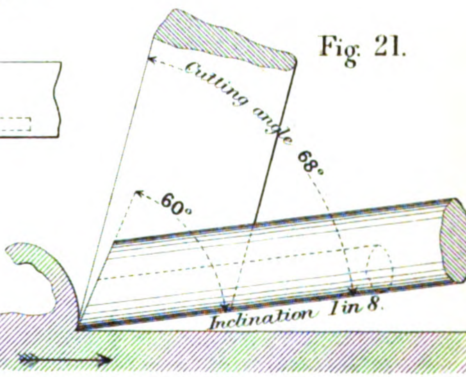


Fig. 22. *Angle Gauge for Swivel Cutters.*

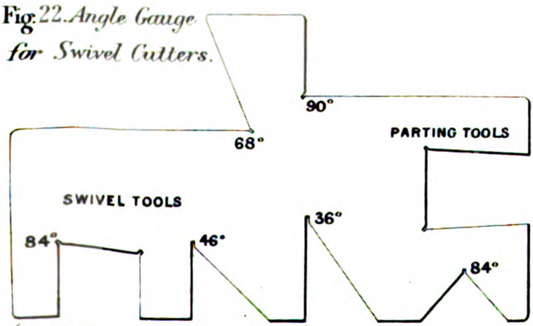
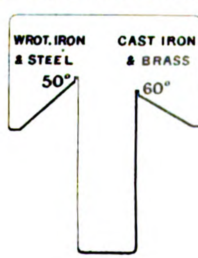


Fig. 23. *Angle Gauge for Round Cutters.*



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Drills.

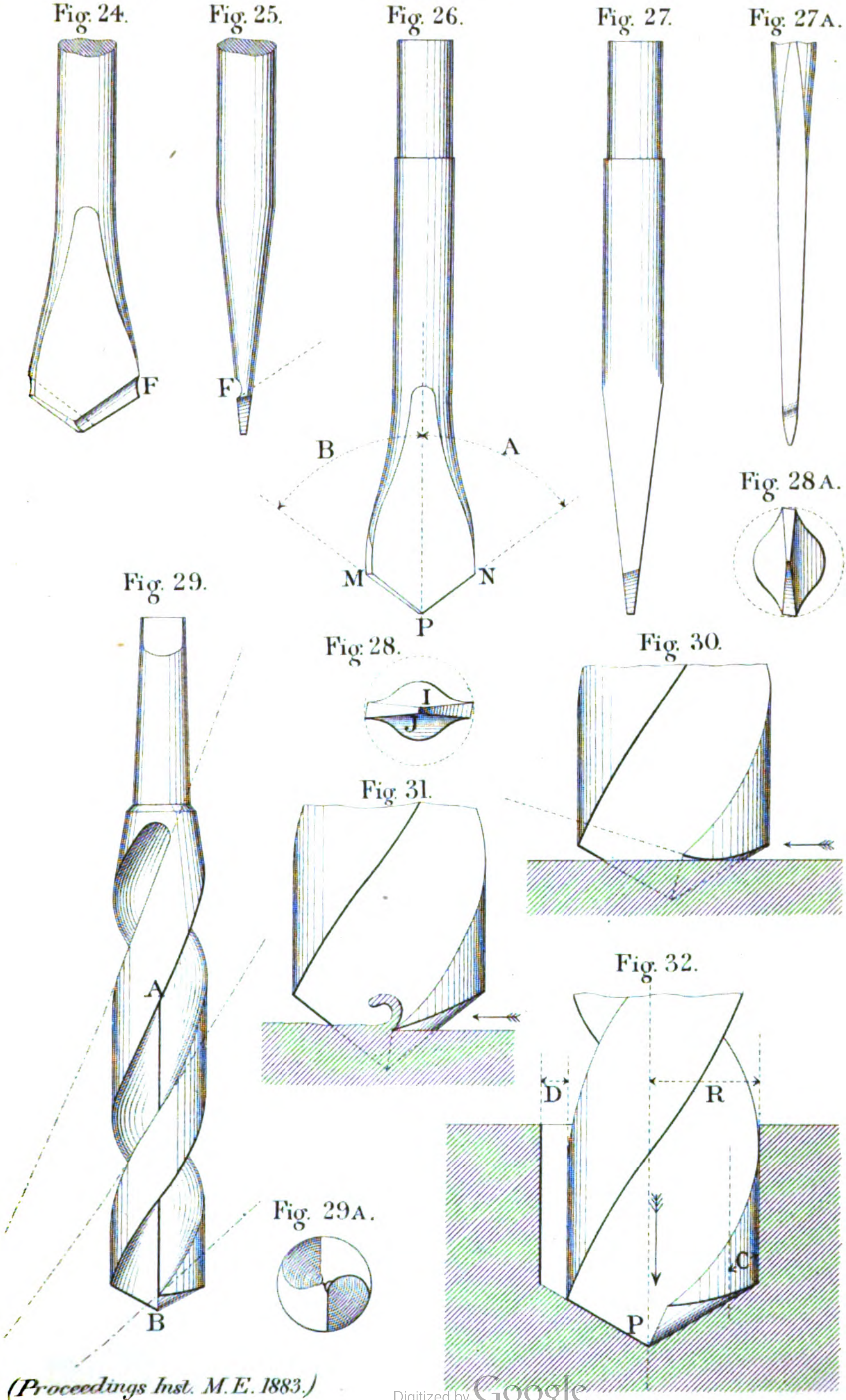
Fig. 24.
F
Fig. 25.
F
Fig. 26.
B
A
M
N
P
Fig. 27.
Fig. 27A.
Fig. 28A.
Fig. 28.
I
J
Fig. 29.
A
B
Fig. 29A.
Fig. 30.
Fig. 31.
Fig. 32.
D
R
C
P

CUTTING OF METALS. *Plate 23.*

Milling Cutters.

Fig. 33.

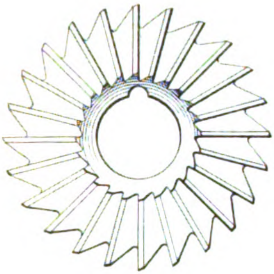

Fig. 34.

Fig. 35.

Fig. 36.

Fig. 38.

Fig. 40.

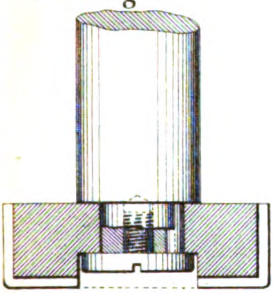

Fig. 37.

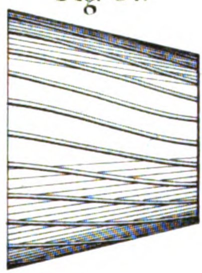

Fig. 39.

Method of Grinding Cutters.

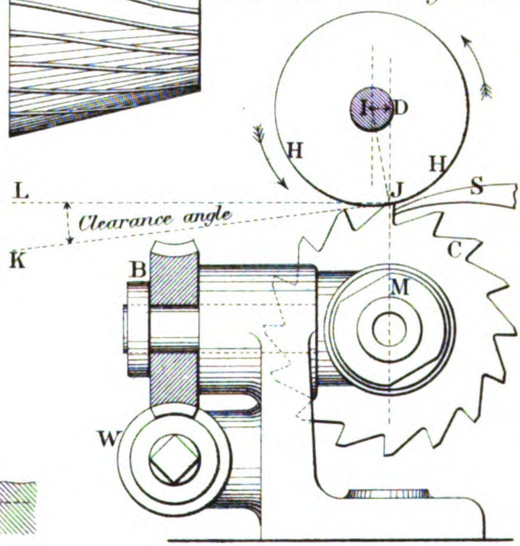

Fig. 41.

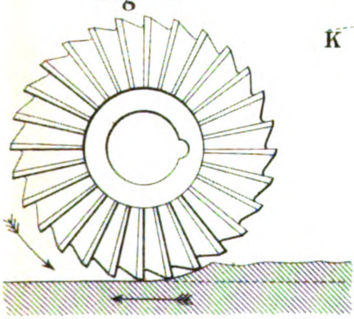

Fig. 42.

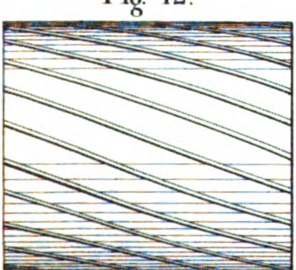

Fig. 43.

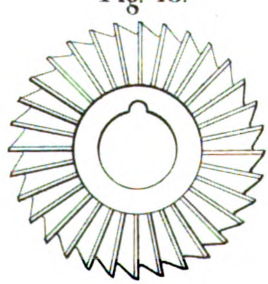

Fig. 44.

Fig. 45.

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Fig. 47. *French Milling Cutter. Scale 1 to 2.*

Fig. 48.

Tool-holders with slight overhang.

Fig. 50. *Elevation.*

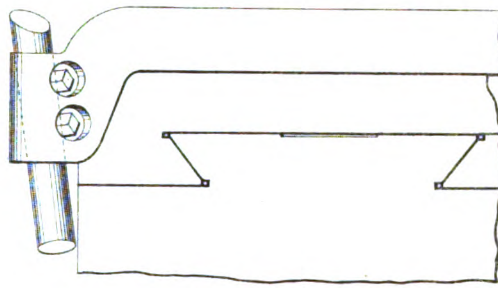


Fig. 51. *Plan.*

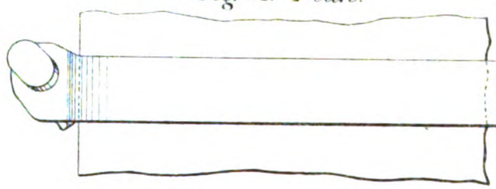


Fig. 52. *Plan.*

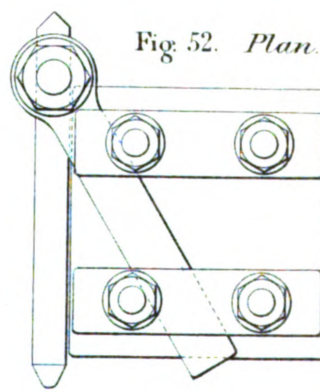


Fig. 49. *Section of Flute, French Cutter. Full size.*

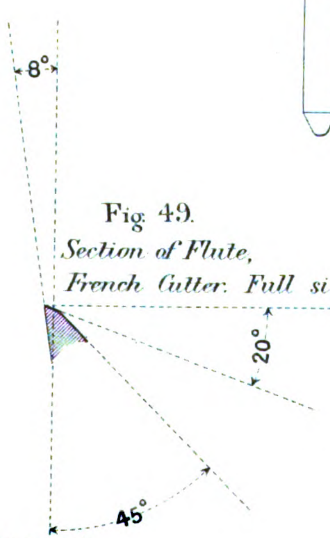
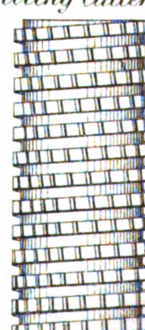
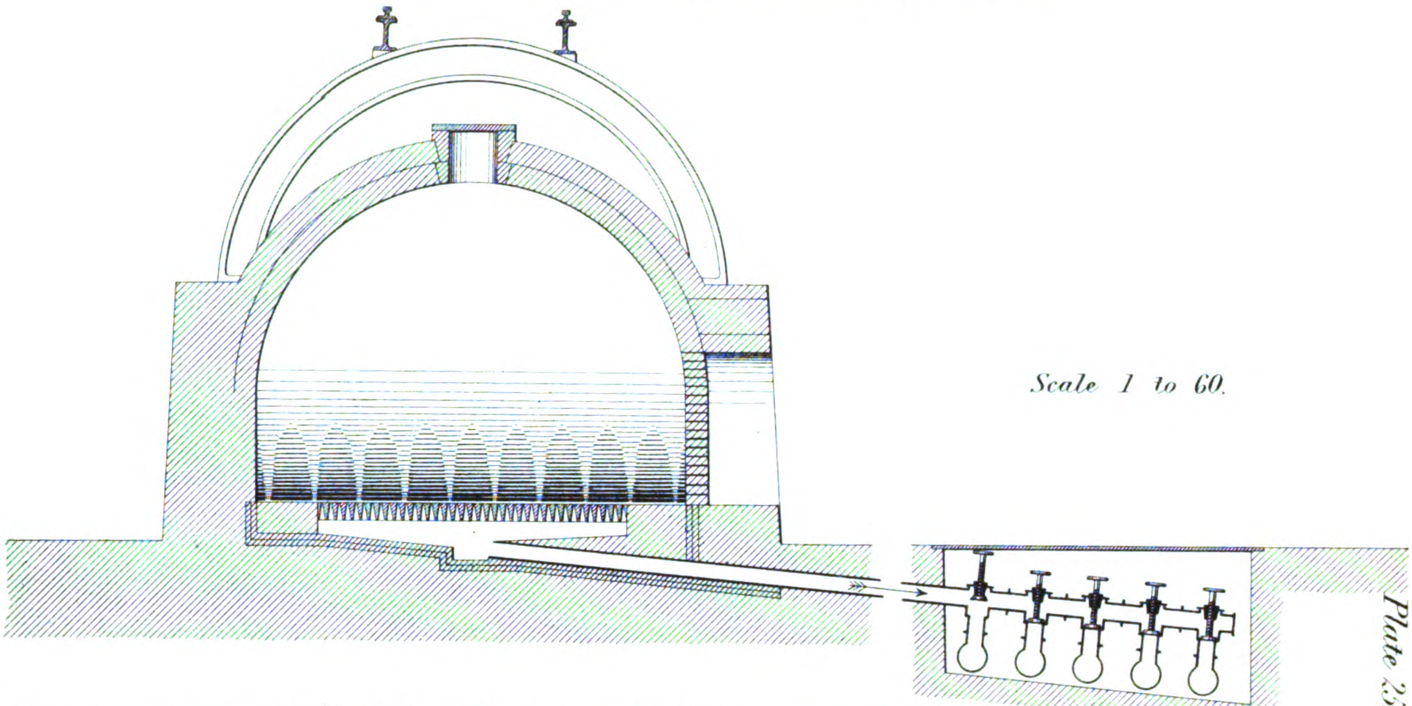


Fig. 46. *Grooved Milling Cutter.*



MANUFACTURE OF COKE.

Fig. 1. *Section of Jameson Coke Apparatus.*



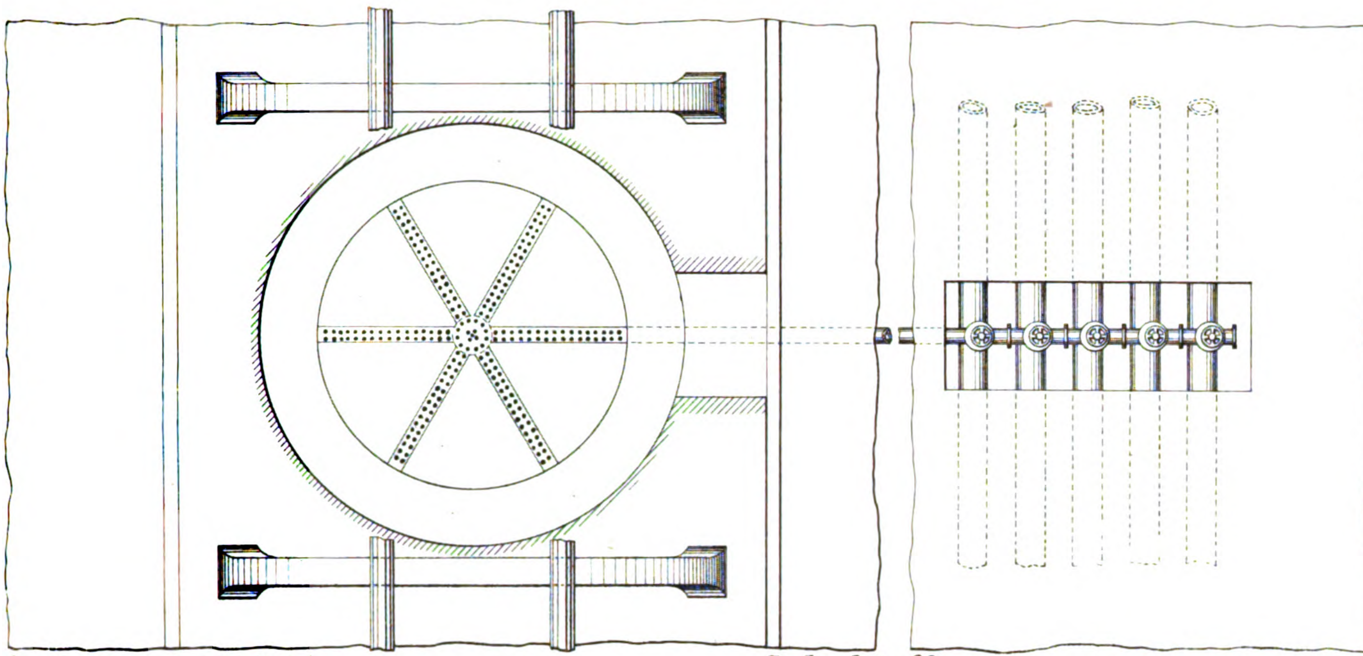
Scale 1 to 60.

Ins.12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 Feet.

Plate 25.

MANUFACTURE OF COKE.

Fig. 2. *Plan of Jameson Coke Apparatus.*



(Proceedings Inst. M.E. 1883.)

Scale 1 to 60.

Plate 26.

Fig. 3.
Section of ordinary Oven.
Scale 1 to 60.

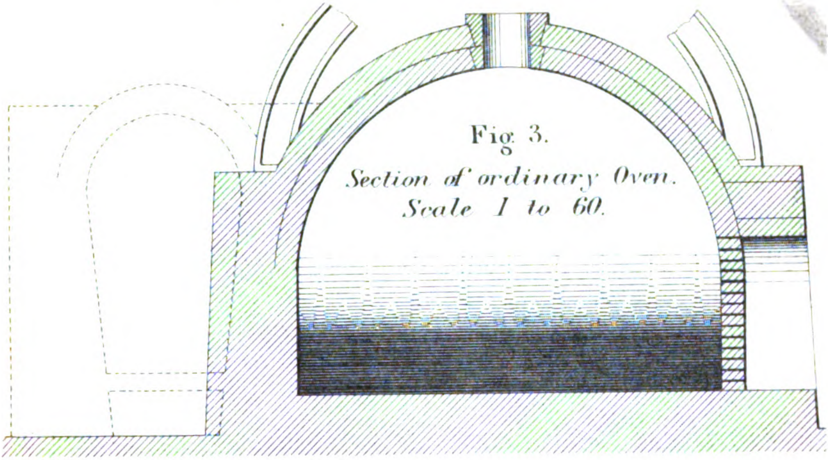


Fig. 4. *Section of Brodie Cochrane Oven.*

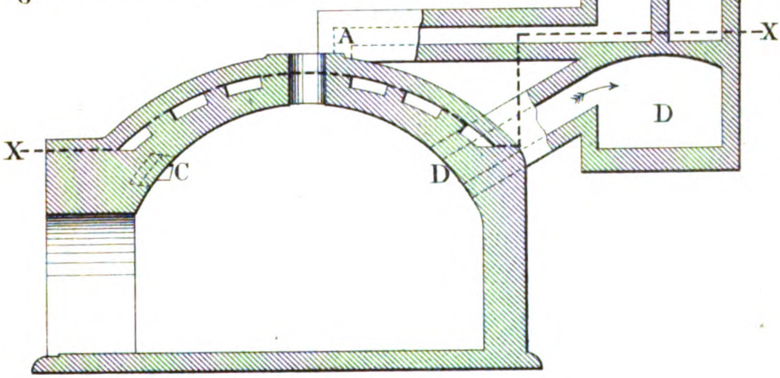
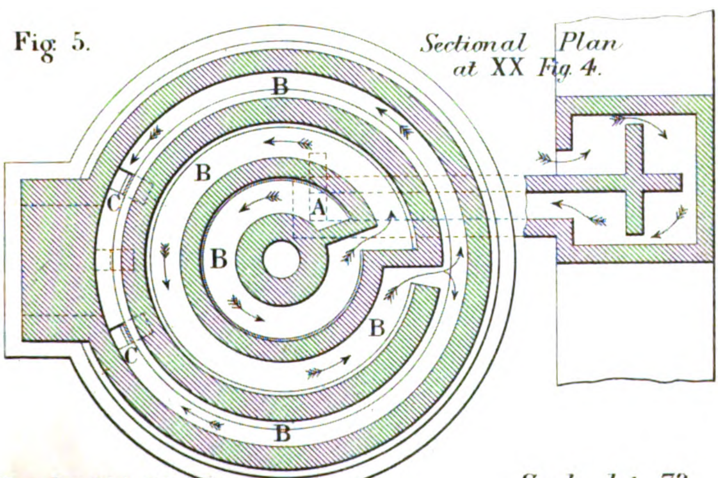


Fig. 5. *Sectional Plan at XX Fig. 4.*



Scale 1 to 72.

MANUFACTURE OF COKE.

Simon-Carvès Coke Oven.

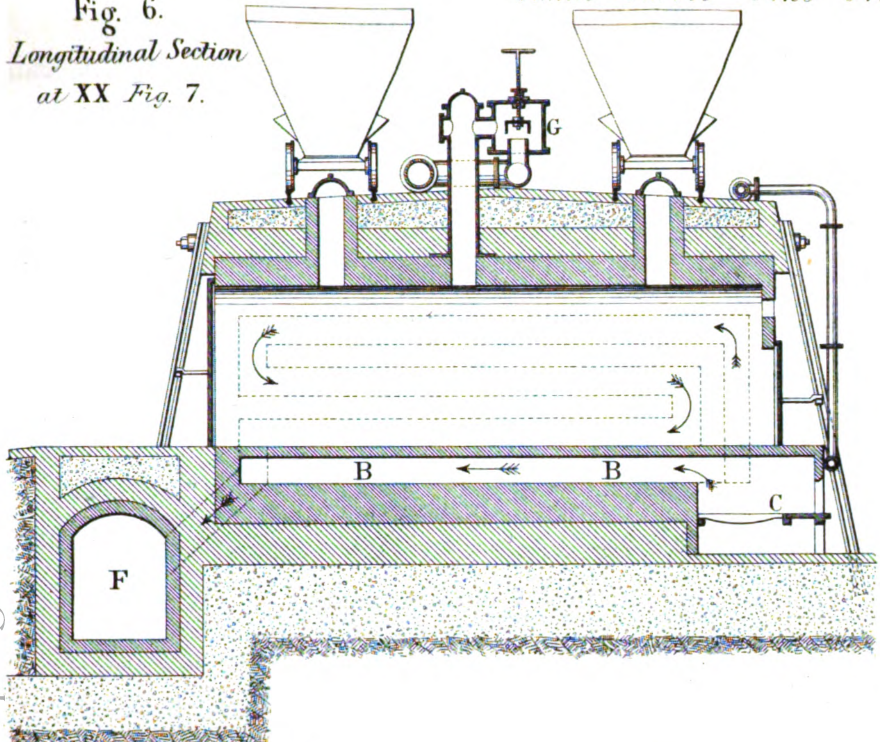


Fig. 6.
Longitudinal Section at XX Fig. 7.

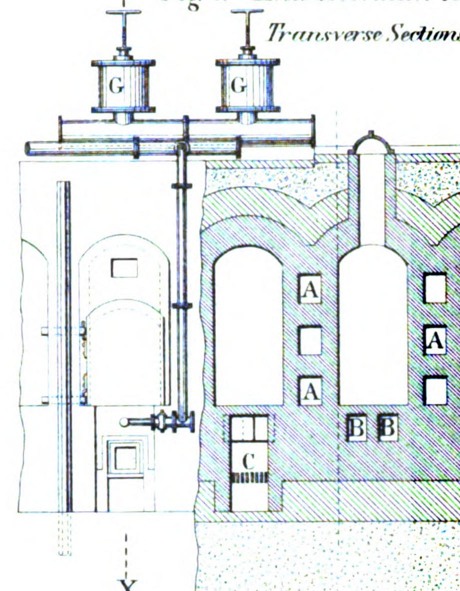


Fig. 7. *End Elevation & Transverse Sections.*

Scale 1 to 96.

(*Proceedings Inst. M. E. 1883.*)

Plate 28.

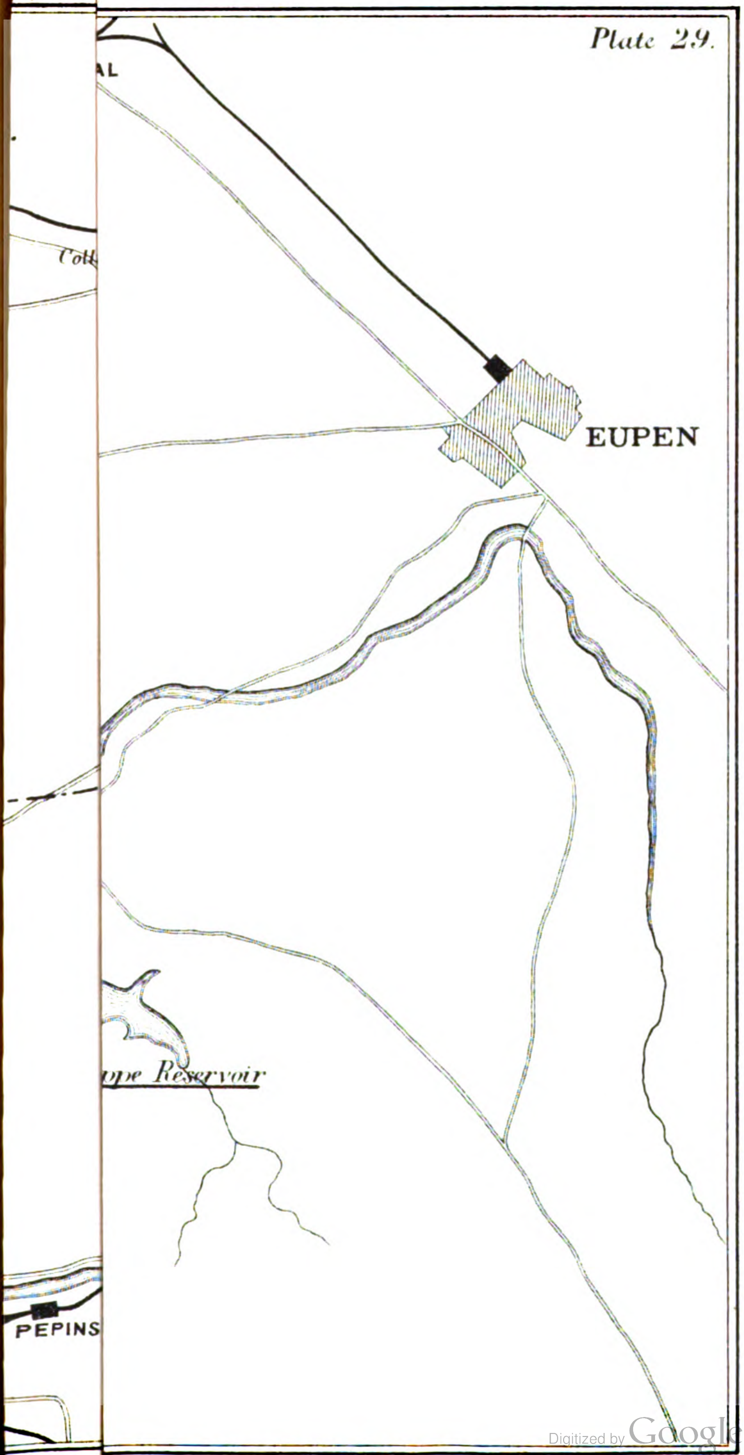


Plate 29.
AL
Coll
EUPEN
ppe Reservoir
PEPINS

Rasping Apparatus.

Fig. 1. *General Elevation.*

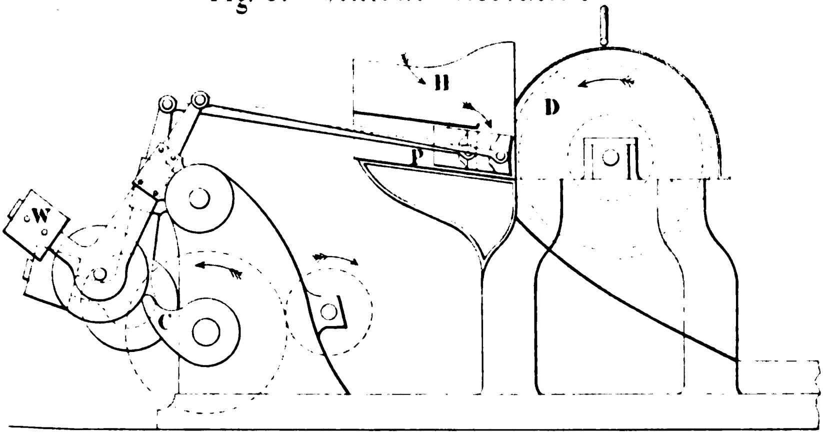


Fig. 2. *Longitudinal Section of Rasping Drum.*
Scale 1 to 10.

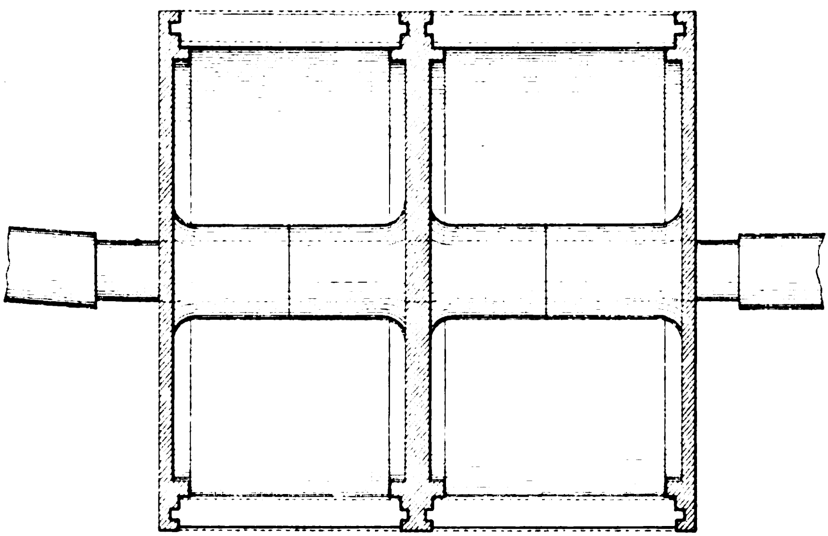
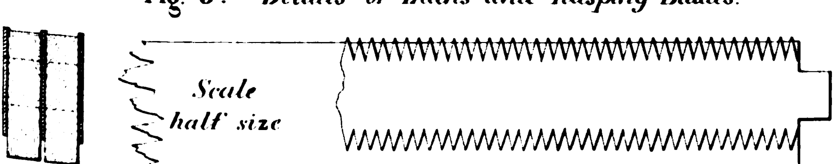


Fig. 3. *Details of Laths and Rasping Blades.*



(Proceedings Inst. M. E. 1883)

BEET-ROOT SUGAR.

Cutter for Cossettes.

Fig. 4. *Section.*
Scale 1 to 60.

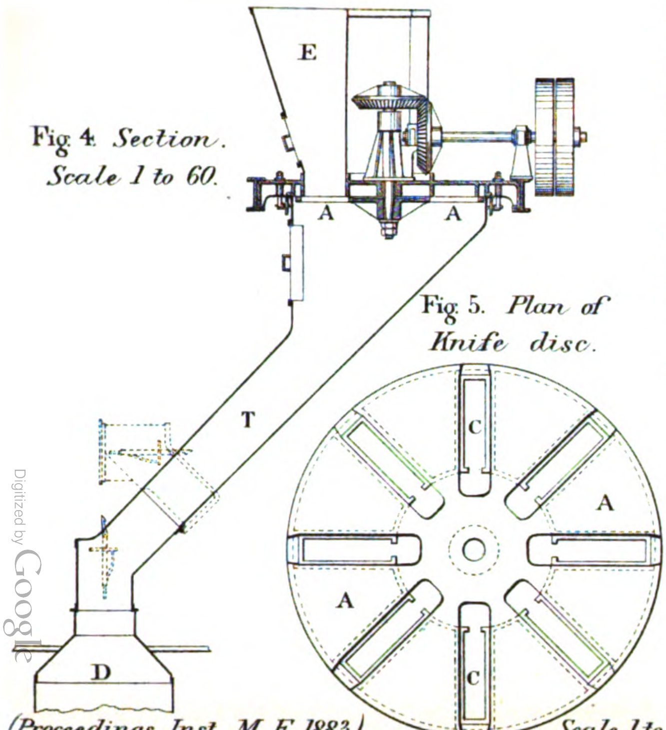


Fig. 5. *Plan of Knife disc.*

Scale 1 to 30.

(Proceedings Inst. M. E. 1883.)

Fig. 10. *Goller Knife.*

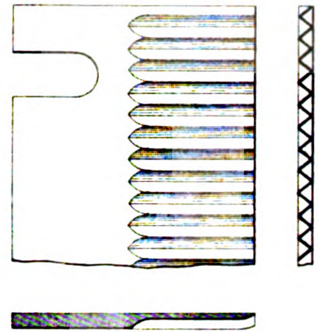
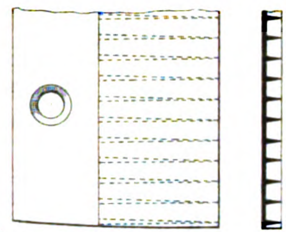


Fig. 9.
Naprawill Knife.



Knife Carrier.

Fig. 6. *Plan.*

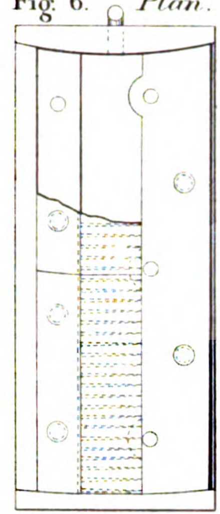


Fig. 7.
Section.

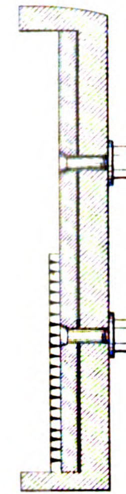
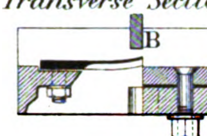
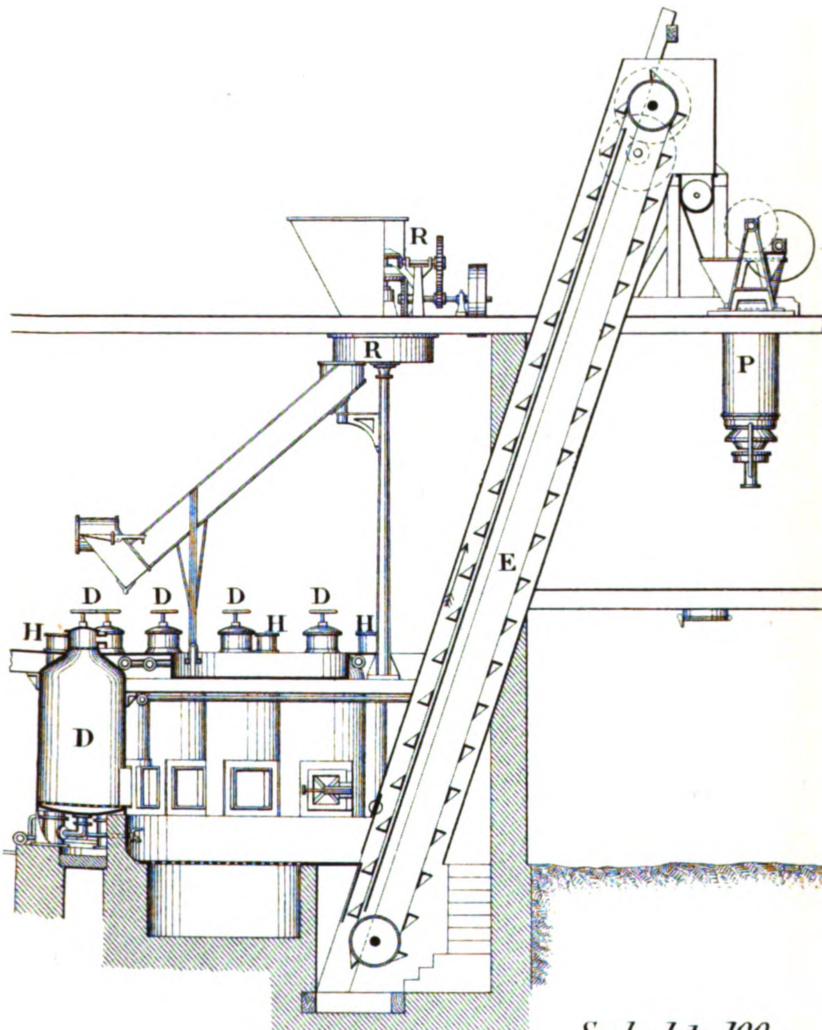


Fig. 8.
Transverse Section.



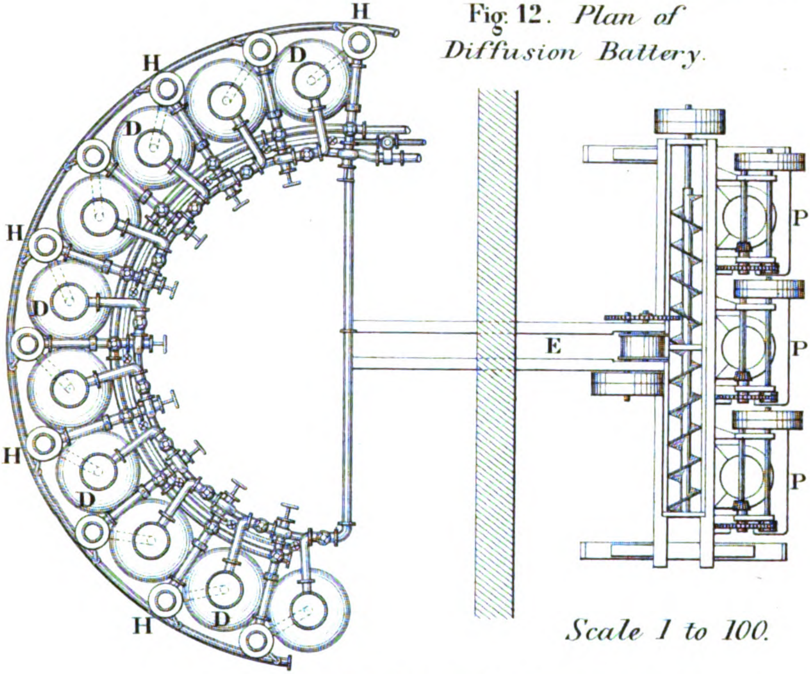
Scale 1 to 5.

Fig. 11. *General Elevation of Diffusion Battery with Klusemann Press.*



Scale 1 to 100.

Fig. 12. *Plan of Diffusion Battery.*



Scale 1 to 100.

Selwig and Lange Press.

Fig. 13.

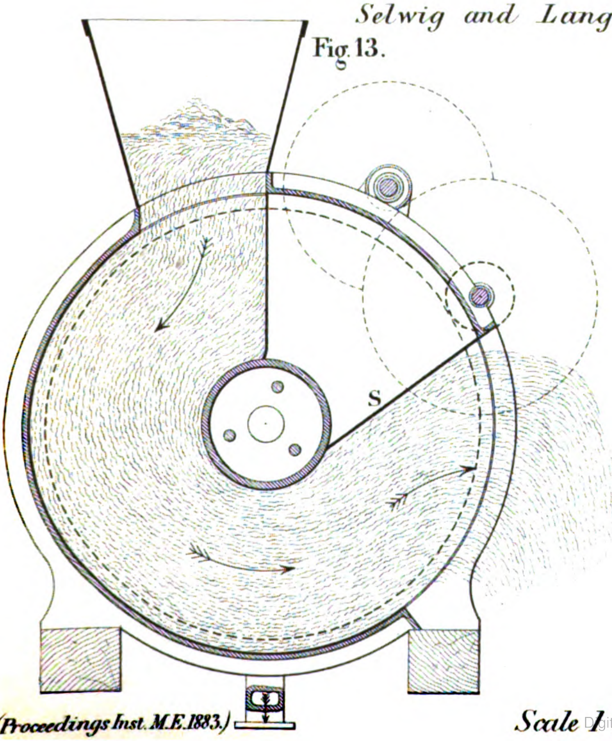
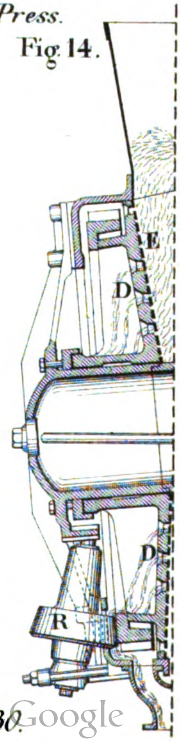


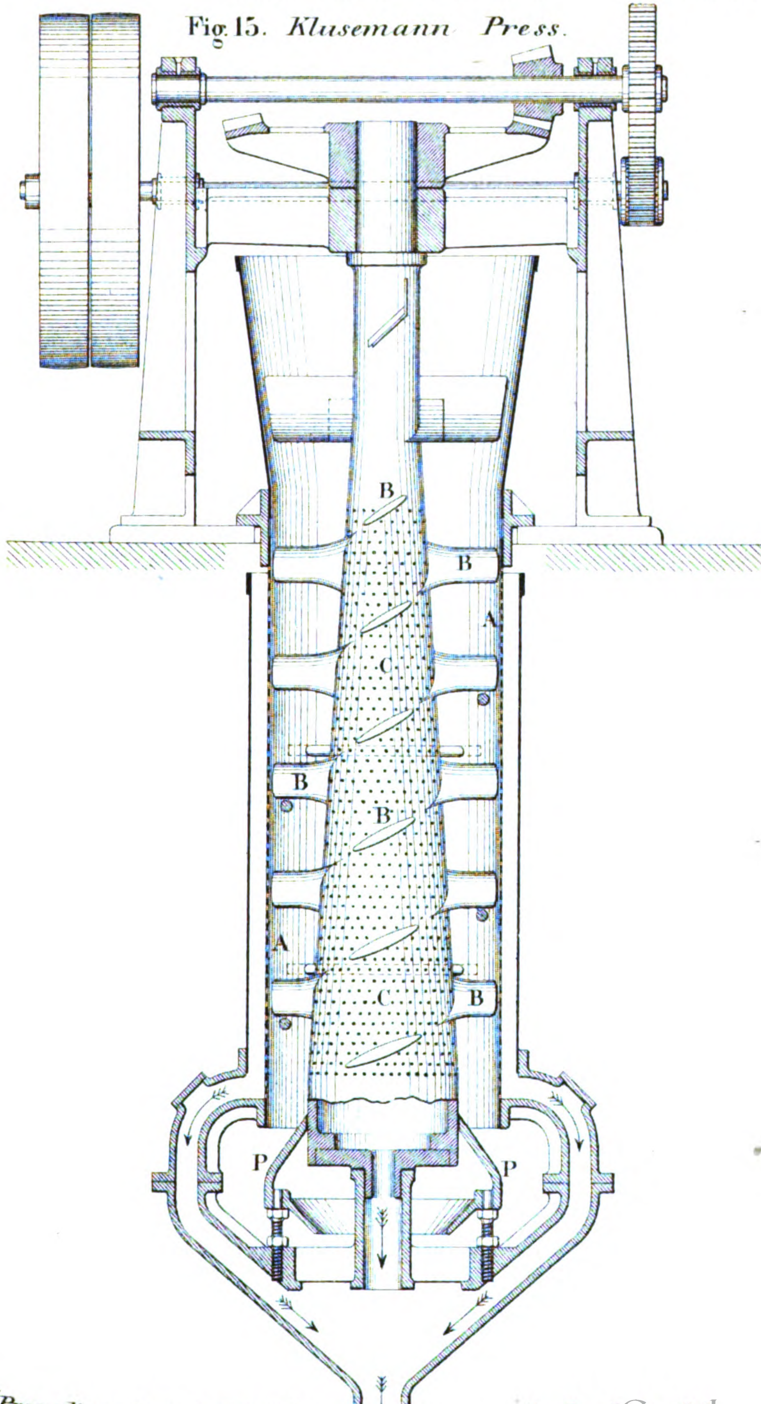
Fig. 14.



(Proceedings Inst. M.E. 1883.)

Scale 1 to 30.

Fig. 15. *Klusemann Press.*



(*Proceedings Inst. M. E. 1883.*)

Scale 1 to 20.

BEET-ROOT SUGAR.

Fig. 16. *Diagram of Carbonatation Plant.*

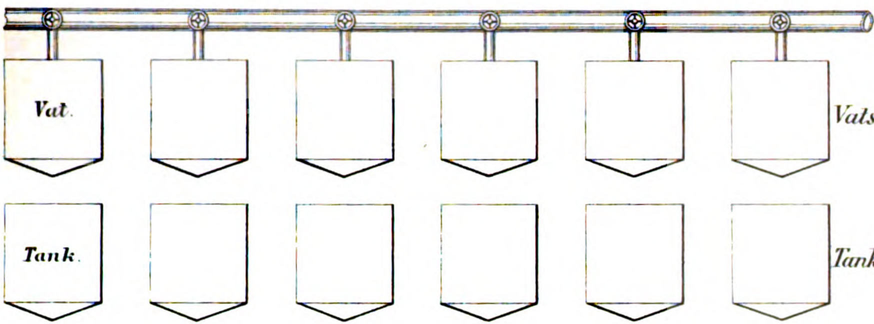


Fig. 17. *Carbonatation Vat.*

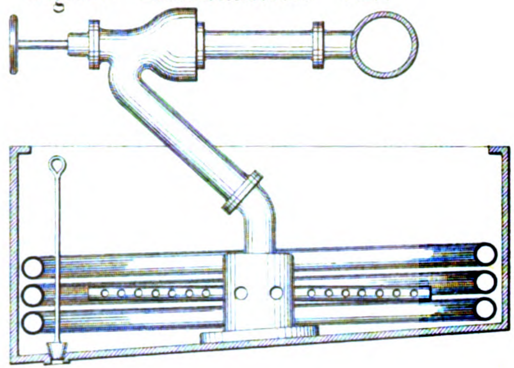


Fig. 19. *Plate for Filtering Press.*

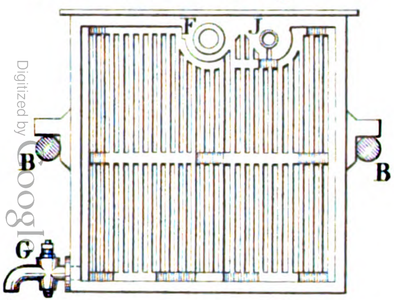


Fig. 20. *Open Frame for Filtering Press.*

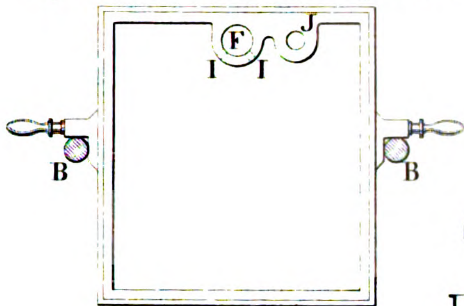
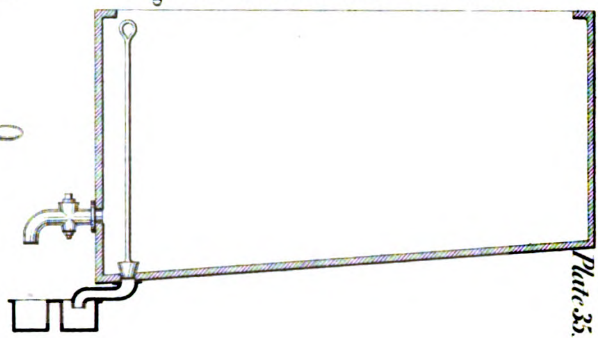


Fig. 18. *Carbonatation Tank.*



(Proceedings Inst. M. E. 1883.)

Fig. 21. *Section and Side View of Filtering Press.*

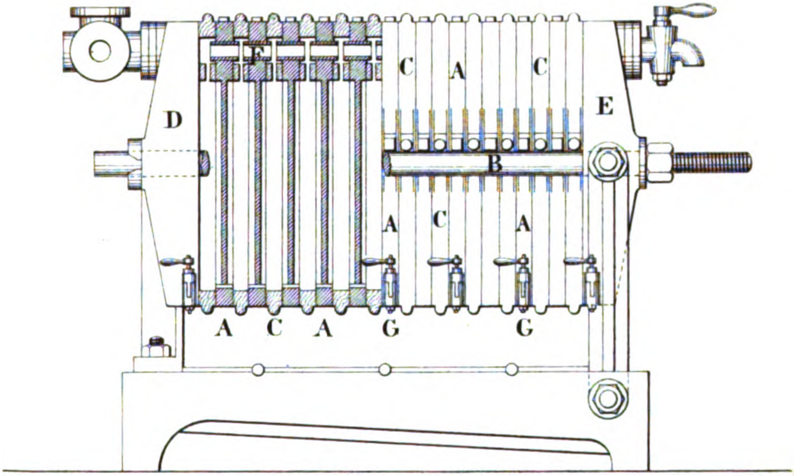
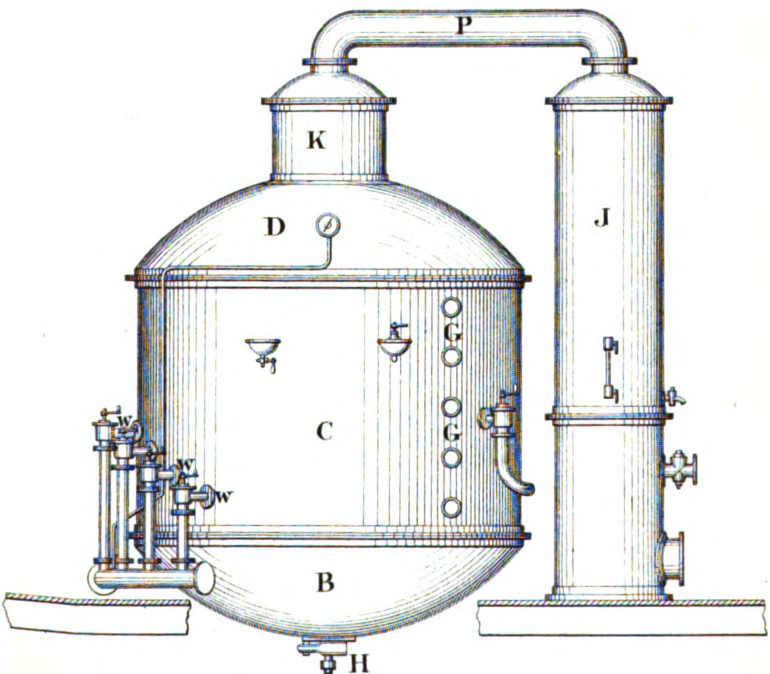


Fig. 22. *Elevation of Sugar Boiler.*

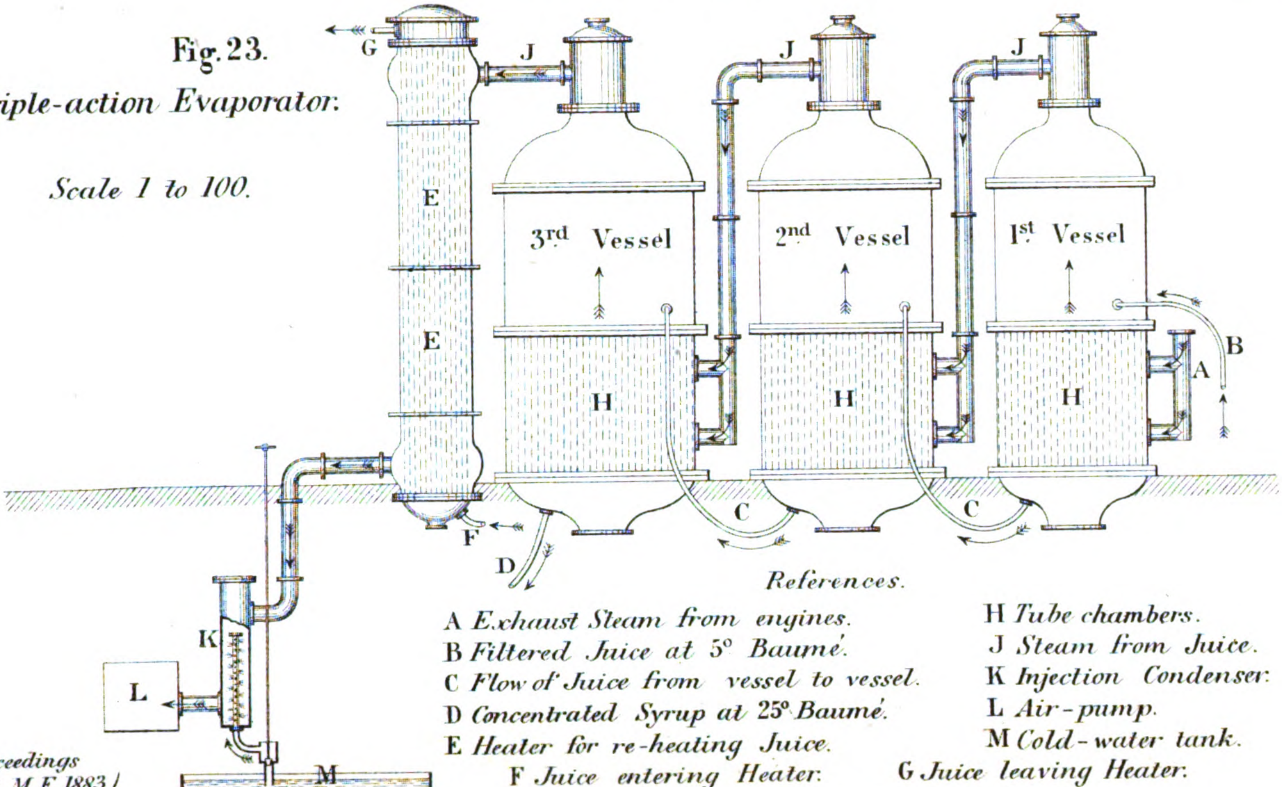


BEET-ROOT SUGAR.

Fig. 23.

Triple-action Evaporator.

Scale 1 to 100.



References.

A Exhaust Steam from engines.
B Filtered Juice at 5° Baumé.
C Flow of Juice from vessel to vessel.
D Concentrated Syrup at 25° Baumé.
E Heater for re-heating Juice.
F Juice entering Heater.
G Juice leaving Heater.
H Tube chambers.
J Steam from Juice.
K Injection Condenser.
L Air-pump.
M Cold-water tank.

Plate 37.

BEET-ROOT SUGAR.

Plate 38.

Osmogene for Molasses.

Fig. 24. *End View.*

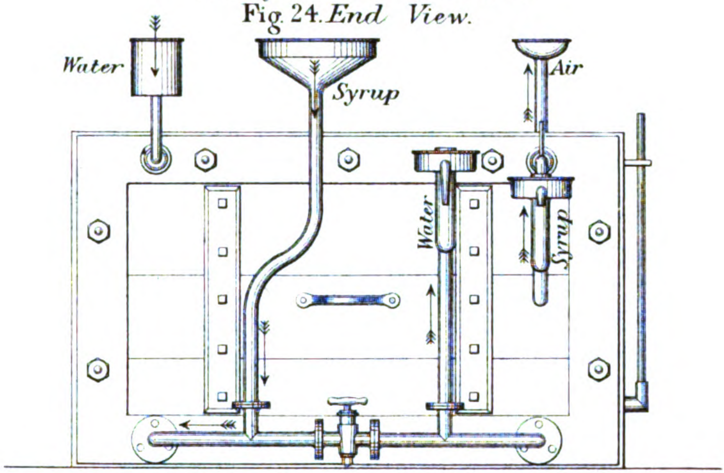


Fig. 25. *Side View and Section.*

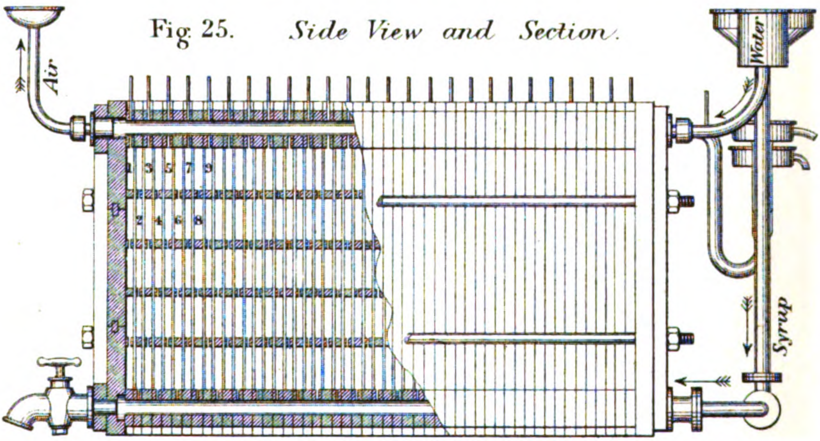


Fig. 26. *Elevation of Frame.*

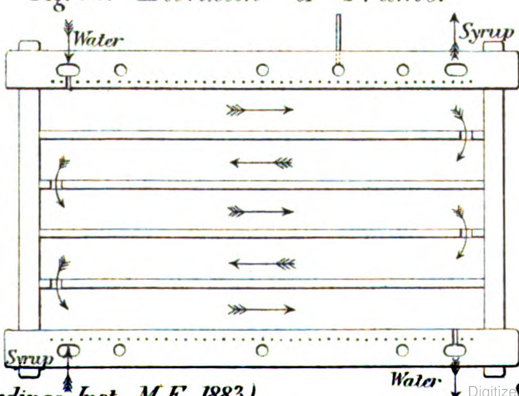
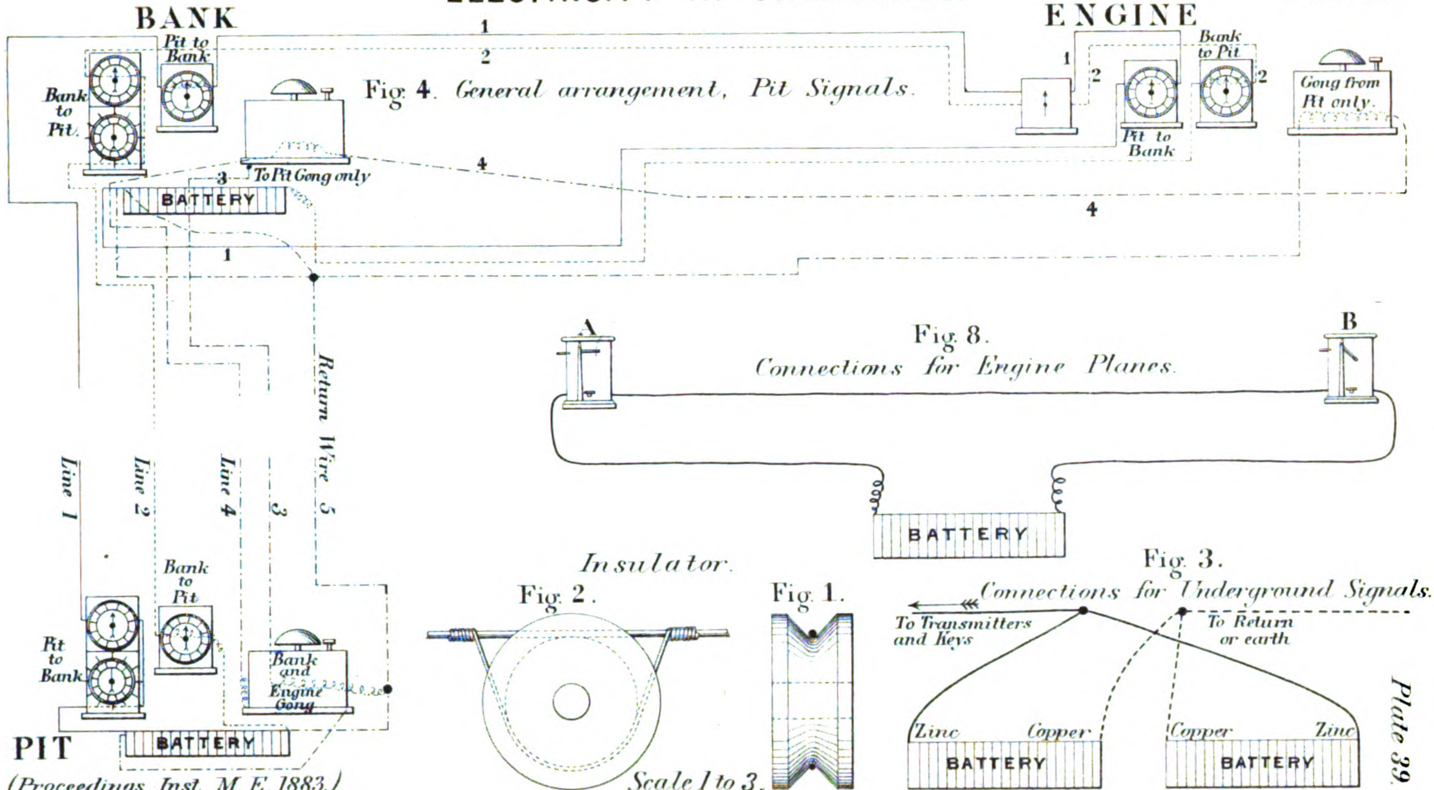


Fig. 27. *Section.*

(Proceedings Inst. M.E. 1883.)

Scale 1 to 15.

ELECTRICITY IN COAL MINES.



(Proceedings Inst. M. E. 1883.)

Plate 39.

ELECTRICITY IN COAL MINES.

Instrument for Engine-plane Signals.

Fig. 6. *Side view of mechanism.*

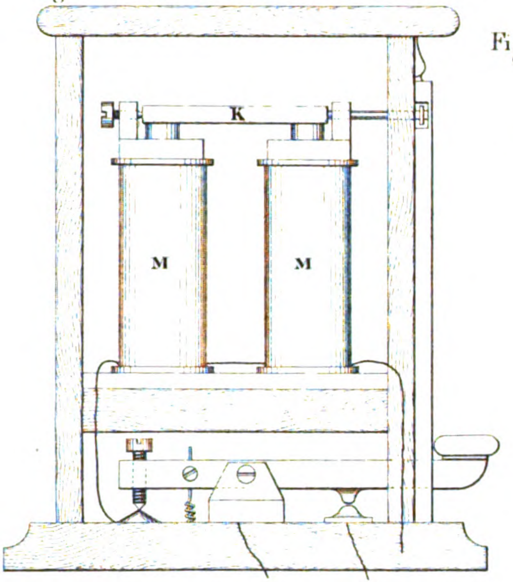


Fig. 5. *End View of Magnets.*

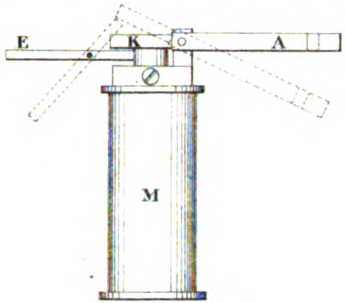
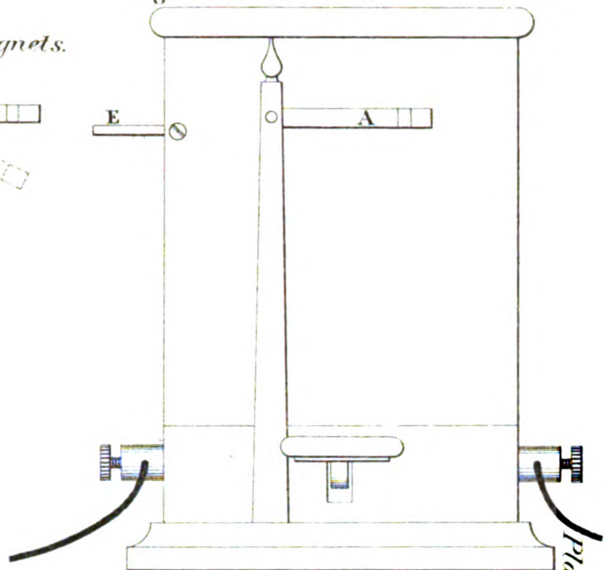


Fig. 7. *Elevation of Instrument.*



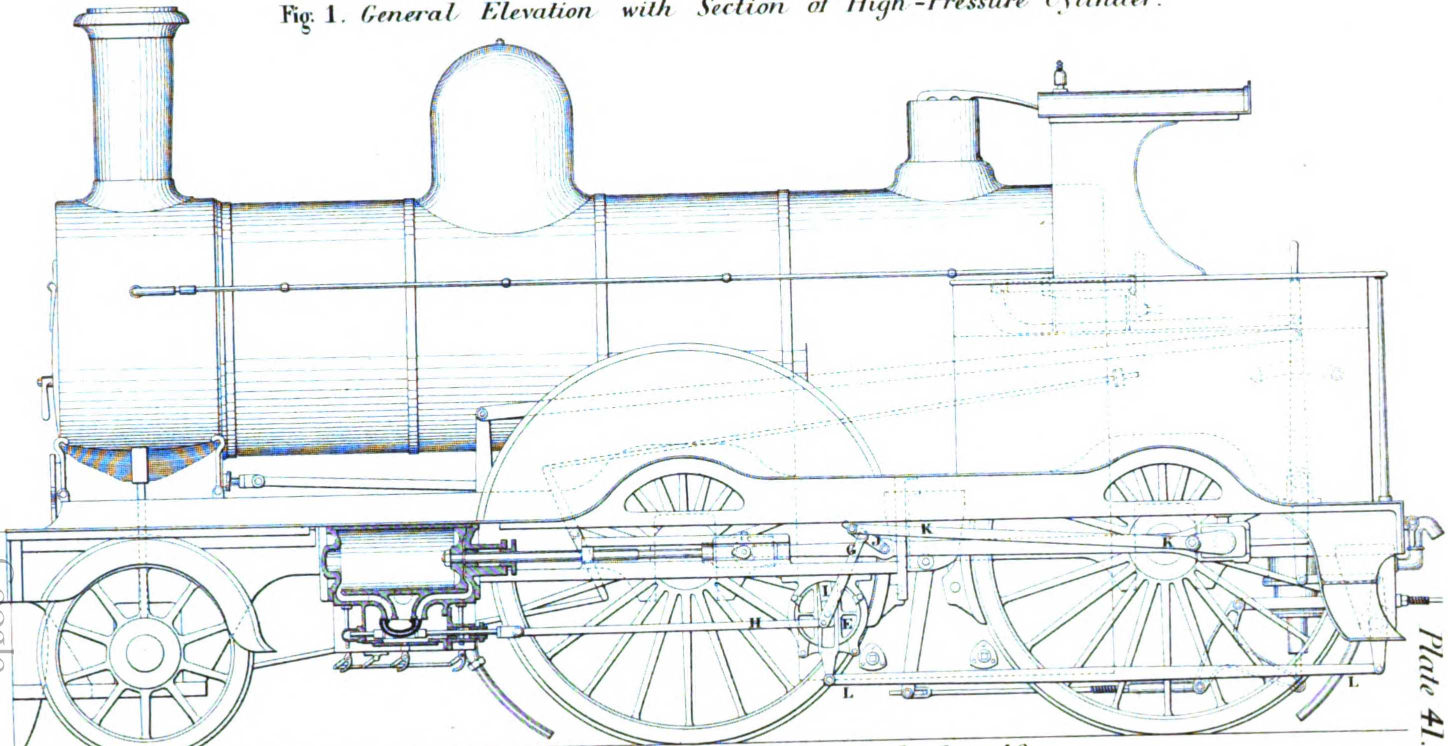
(*Proceedings Inst. M. E. 1883.*)

Scale 1 to 3.

Plate 40.

COMPOUND LOCOMOTIVES.

Fig. 1. *General Elevation with Section of High-Pressure Cylinder.*

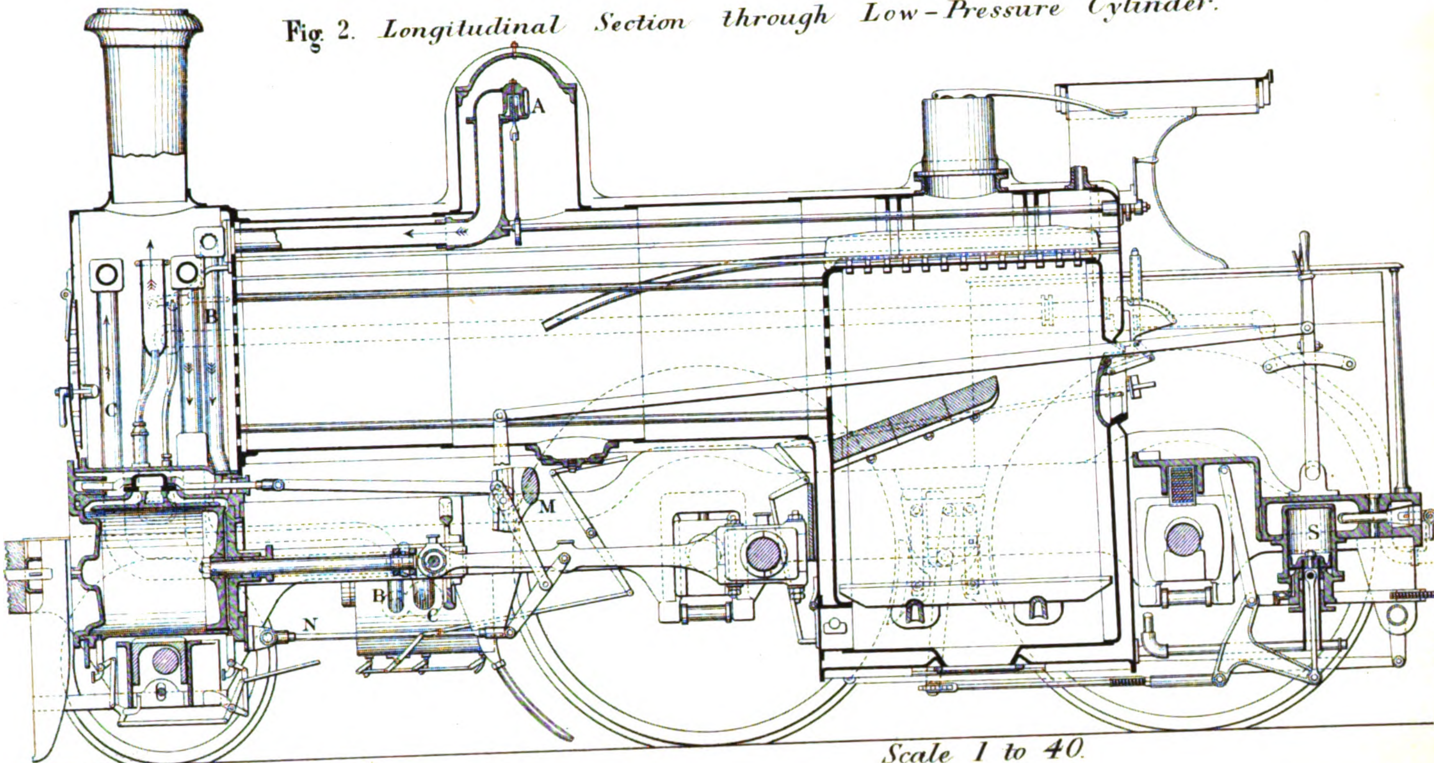


Scale 1 to 40.

Plate 41.

COMPOUND LOCOMOTIVES.

Fig. 2. *Longitudinal Section through Low-Pressure Cylinder.*



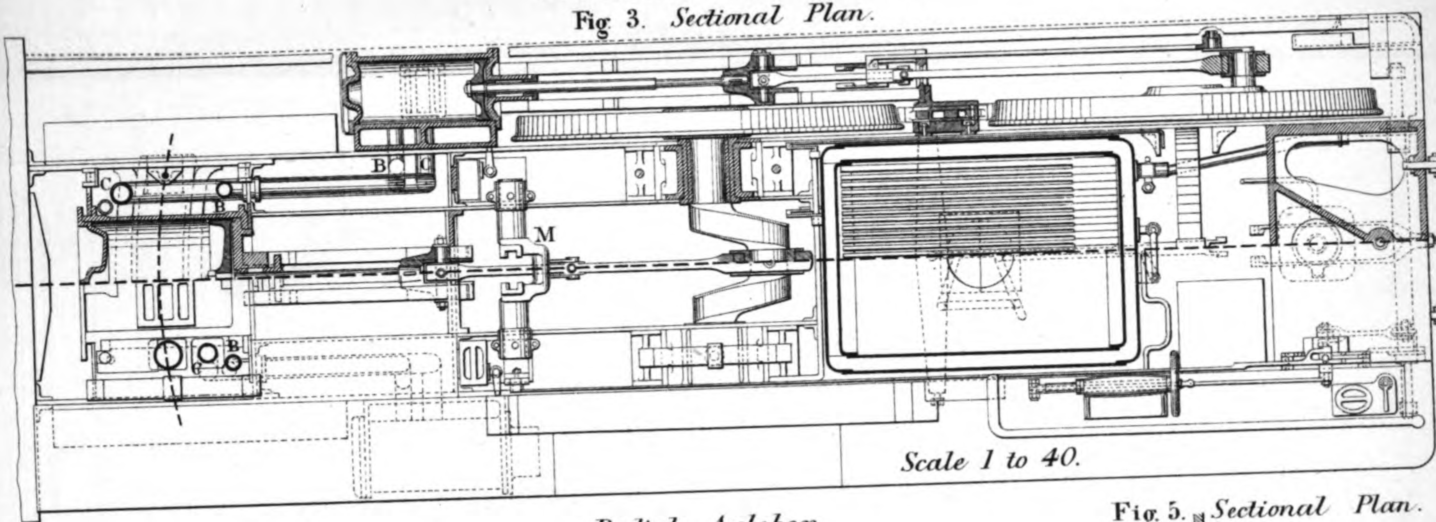
Scale 1 to 40.

(Proceedings Inst. M. E. 1883.)

Plate 42.

COMPOUND LOCOMOTIVES.

Fig. 3. *Sectional Plan.*



Radial Axlebox.

Fig. 4. *Sectional Elevation.*

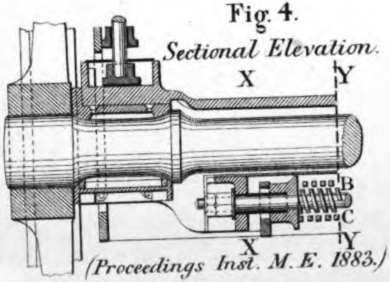


Fig. 6. *Section at XX.*

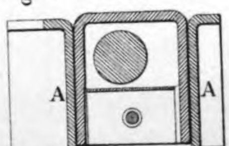


Fig. 7. *Section at YY.*

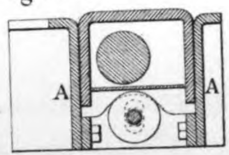
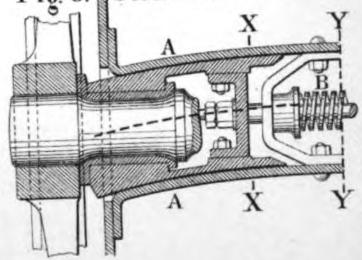


Fig. 5. *Sectional Plan.*



Scale 1 to 20.

(Proceedings Inst. M. E. 1883.)

Plate 43.

Indicator Diagrams.

Fig. 8. *Speed, slow. Full gear.*

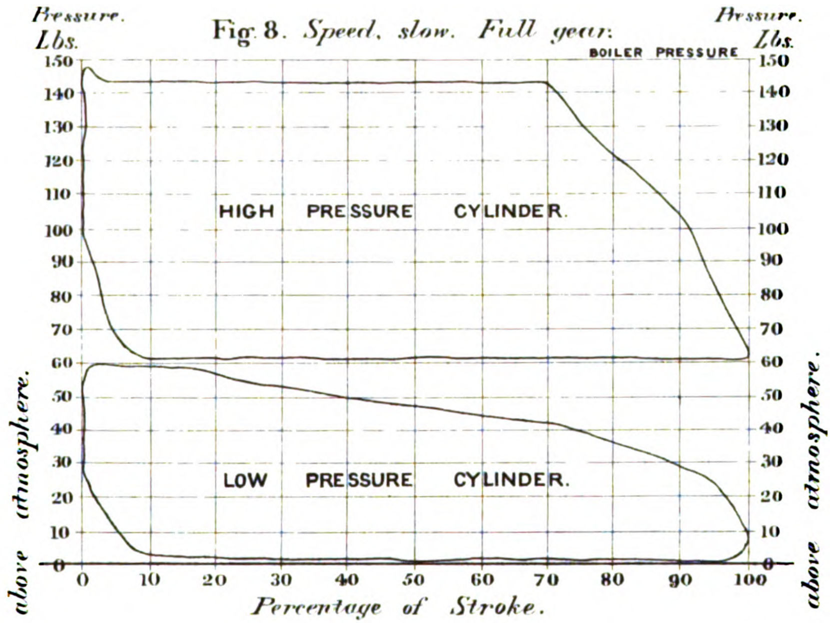
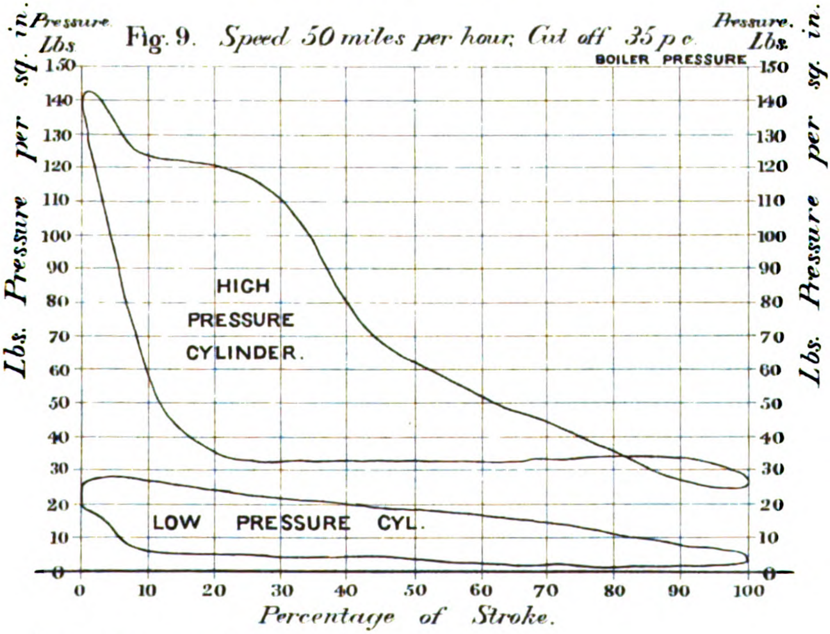
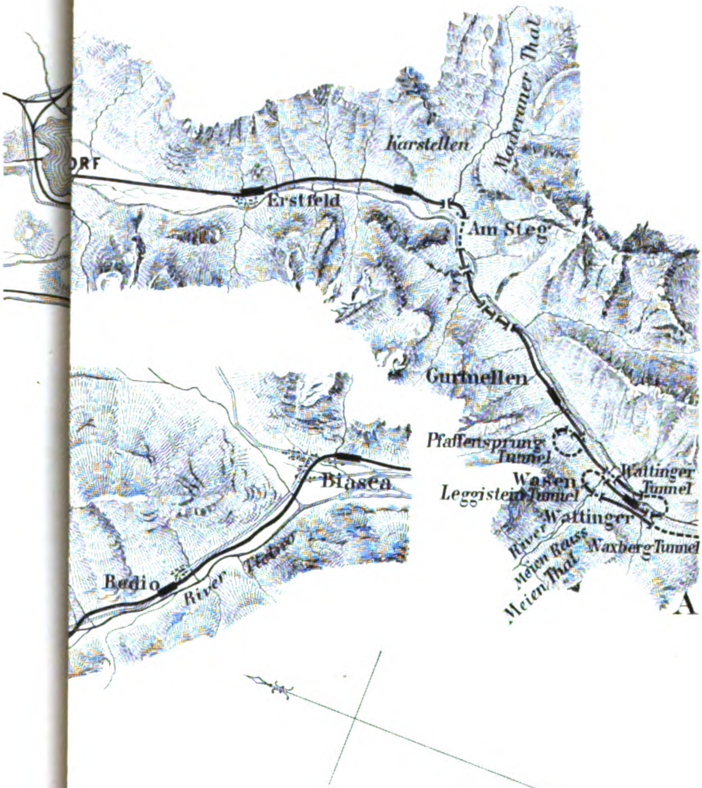


Fig. 9. *Speed 50 miles per hour; Cut off 35 p.c.*



(Proceedings Inst. M.E. 1883)



A
Gösc

RD RAILWAY.

ailway, from Lucerne to Biasca.

1 to 200,000.

S^T GOTHARD RAILWAY.

Fig. 2. Side-slope in cutting.

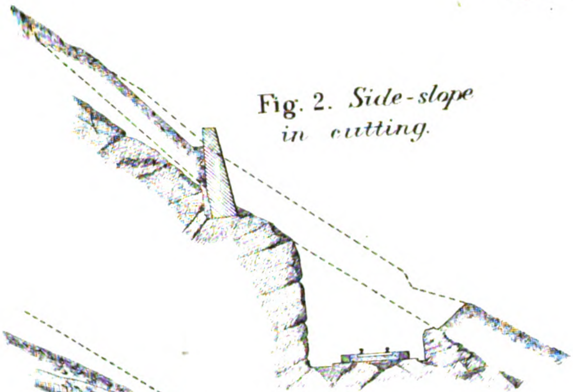
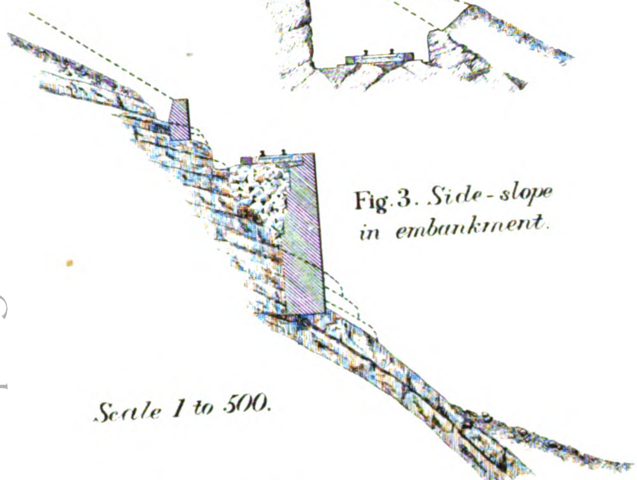


Fig. 3. Side-slope in embankment.



Scale 1 to 500.

Fig. 4. Masonry Viaduct.

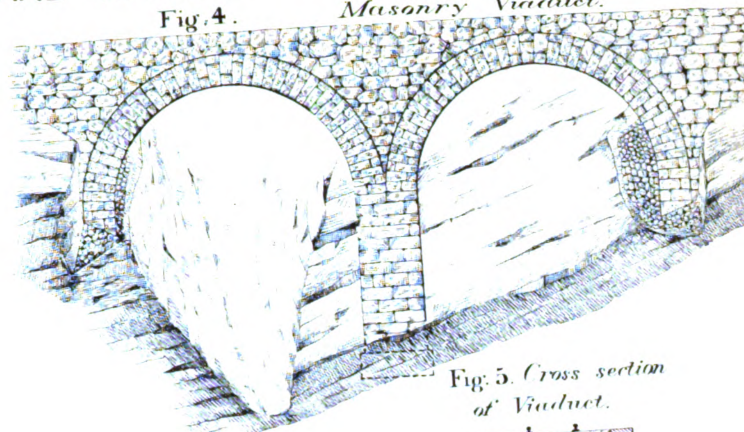
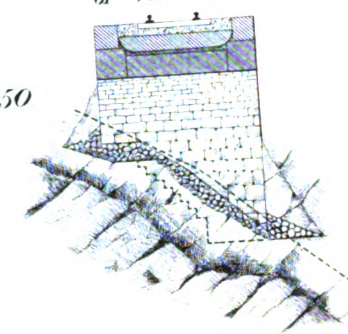


Fig. 5. Cross section of Viaduct.



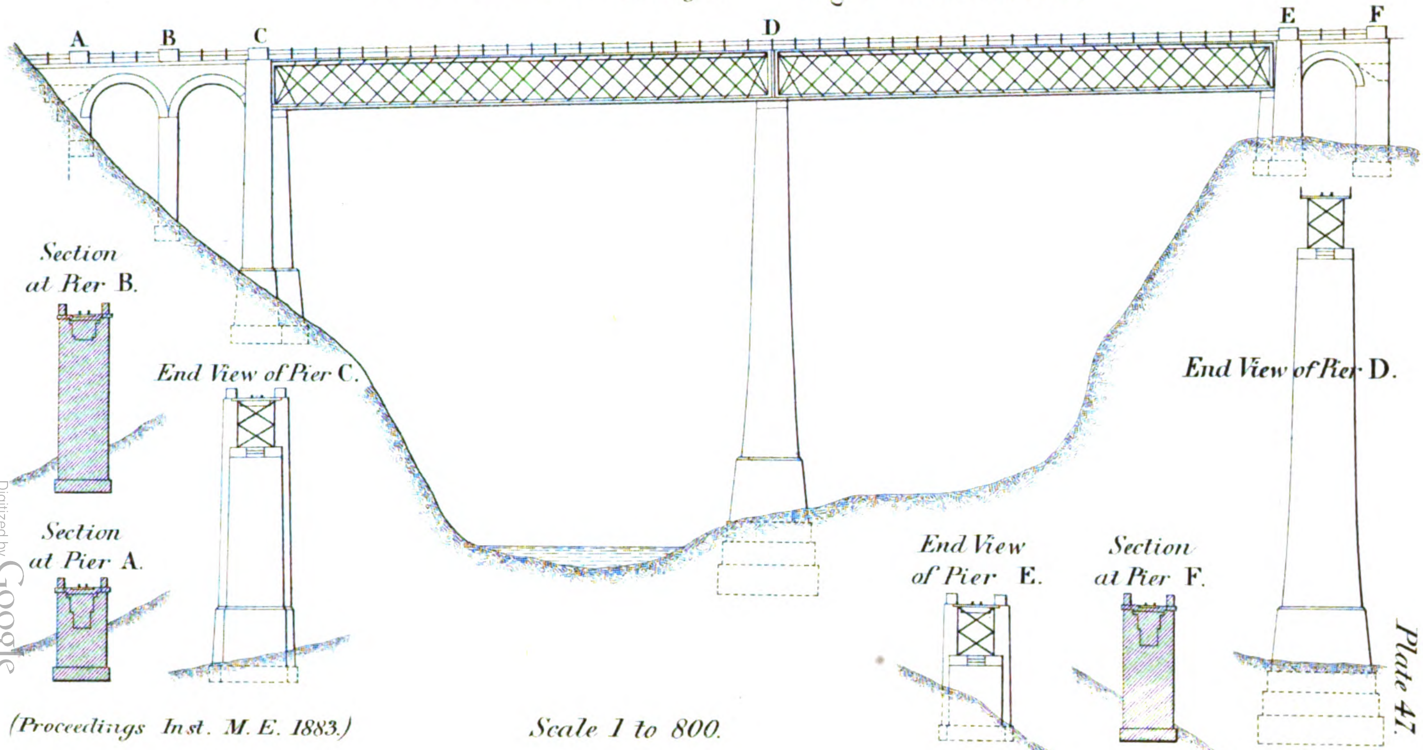
Scale 1 to 250

(Proceedings Inst. M.E. 1883)

Plate 46.

S^T GOTHARD RAILWAY.

Kärstellenbach Bridge. Fig. 6. Elevation.



Scale 1 to 800.

(Proceedings Inst. M. E. 1883.)

St GOTHARD RAILWAY.

Brandt Drill.

Fig. 8. Plan.

Scale 1 to 10.

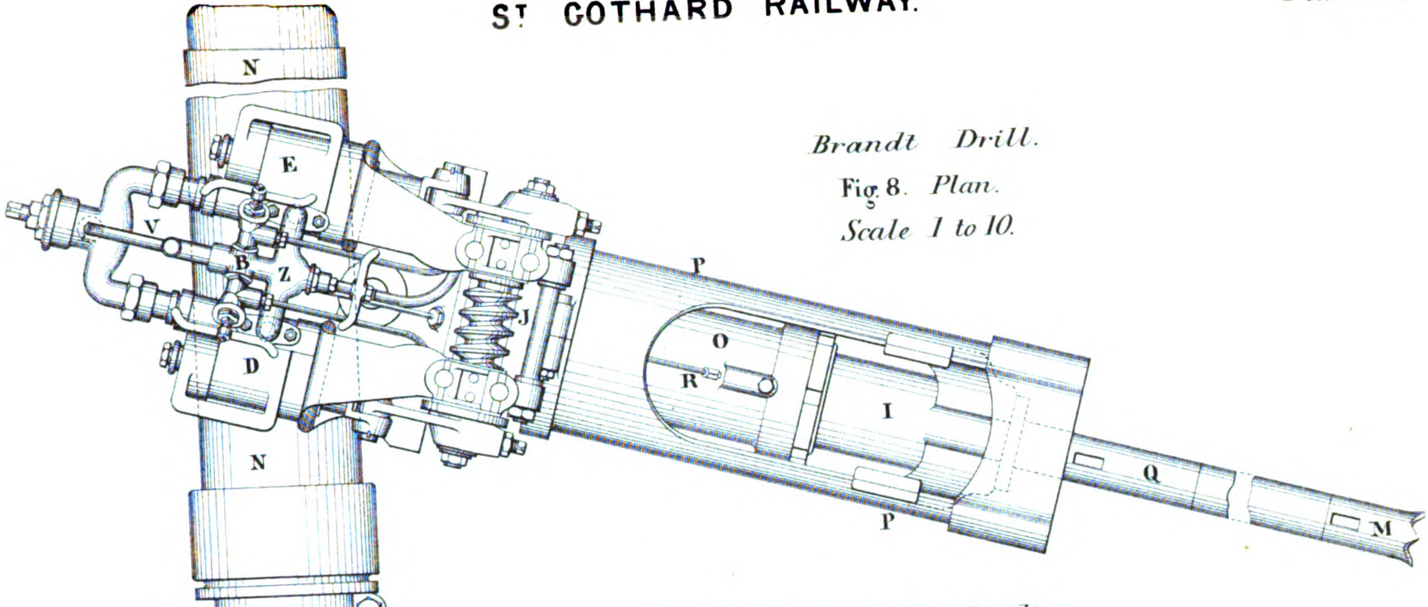


Fig. 7. Section of Pipe Coupling.

Scale 1 to 4.

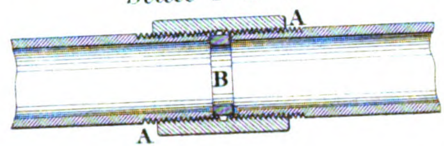
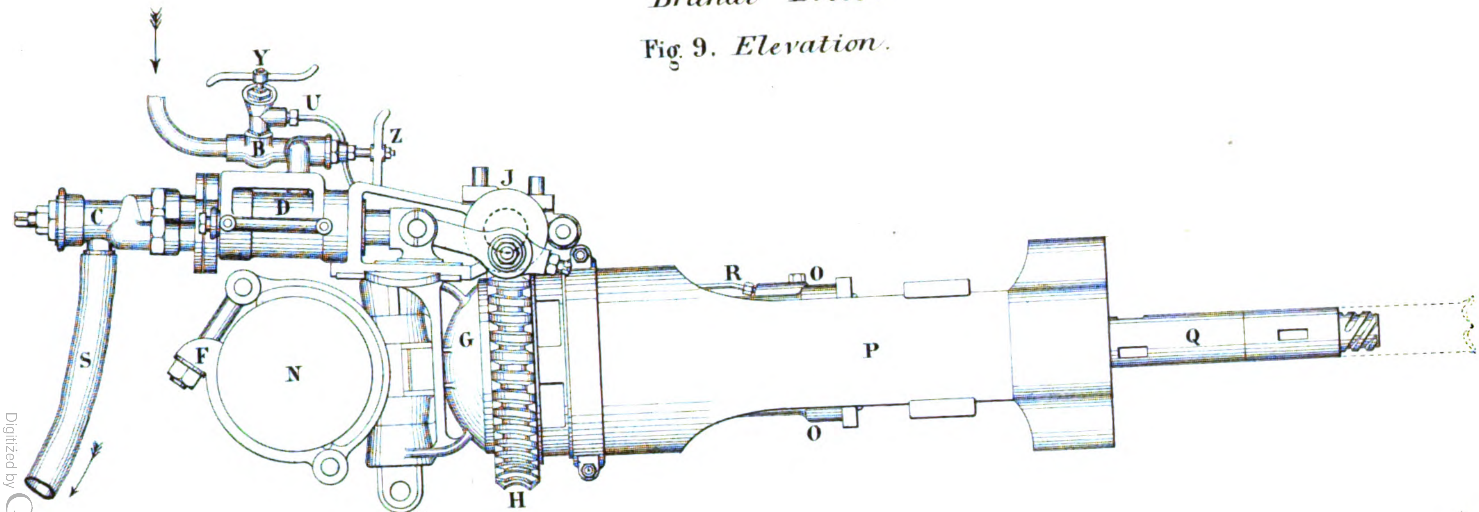


Plate 48.

ST. GOTHARD RAILWAY.

Brandt Drill.

Fig. 9. Elevation.



Scale 1 to 10.

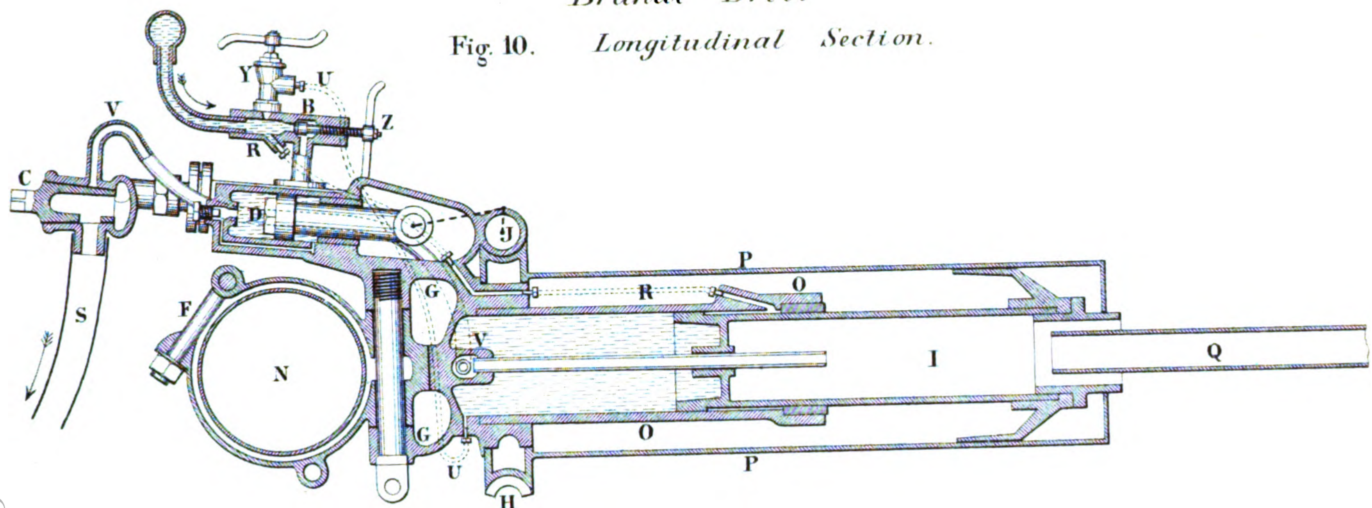
(Proceedings Inst. M.E. 1883.)

Plate 49.

St. GOTHARD RAILWAY.

Brandt Drill

Fig. 10. Longitudinal Section.



Scale 1 to 10.

Plate 50.

ANTWERP HARBOUR WORKS. *Plate 51.*

Fig. 1. *Plan of Quays and Docks.*

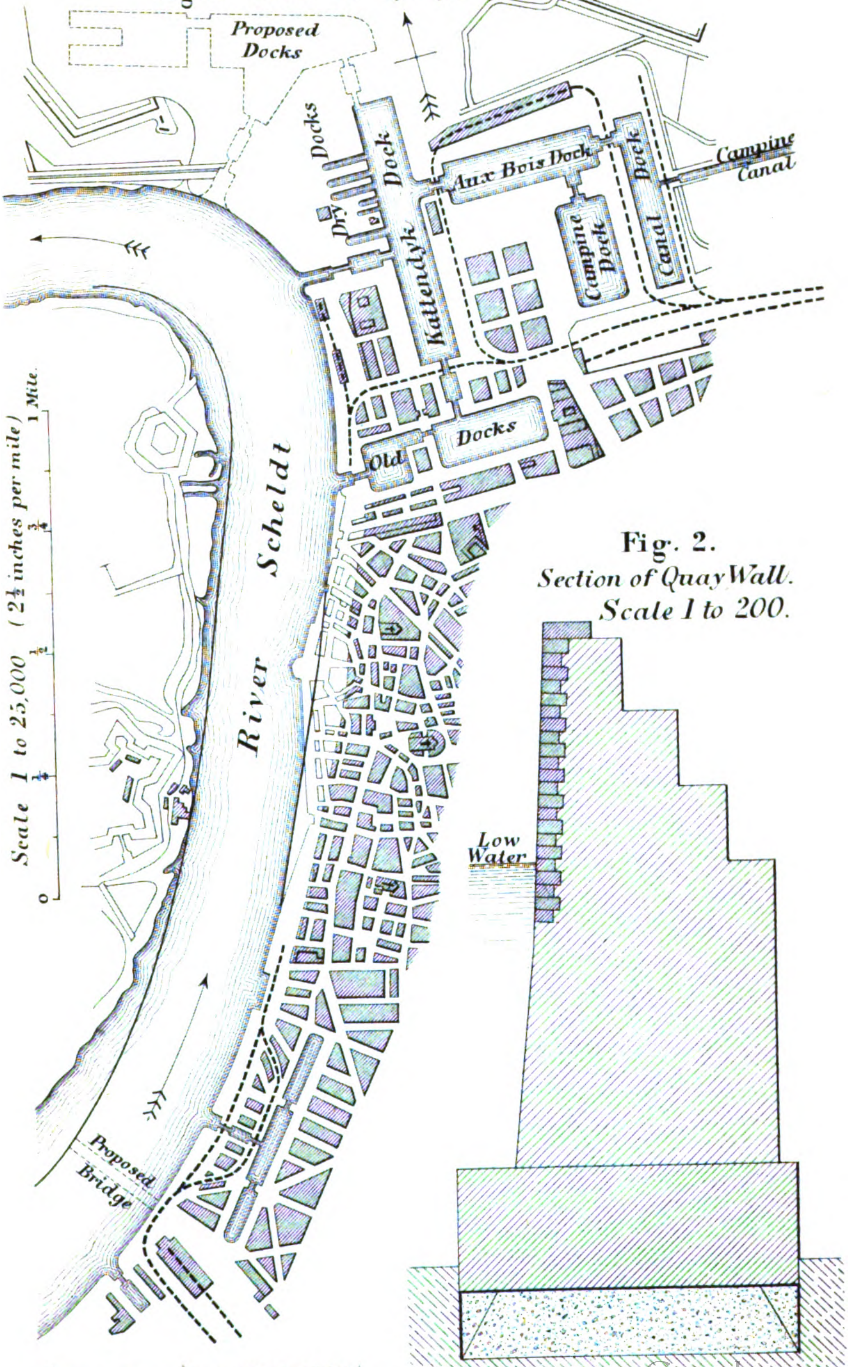


Fig. 2.
Section of Quay Wall.
Scale 1 to 200.

(Proceedings Inst. M.E. 1883)

ANTWERP HARBOUR WORKS.

Caisson, Moveable Cofferdam, and Floating Framework.

Fig. 3. Longitudinal Section.

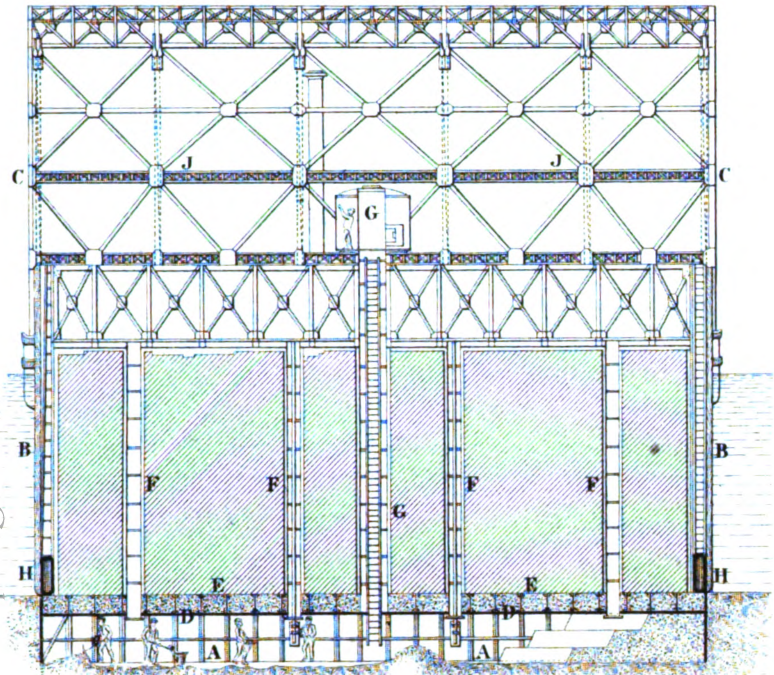
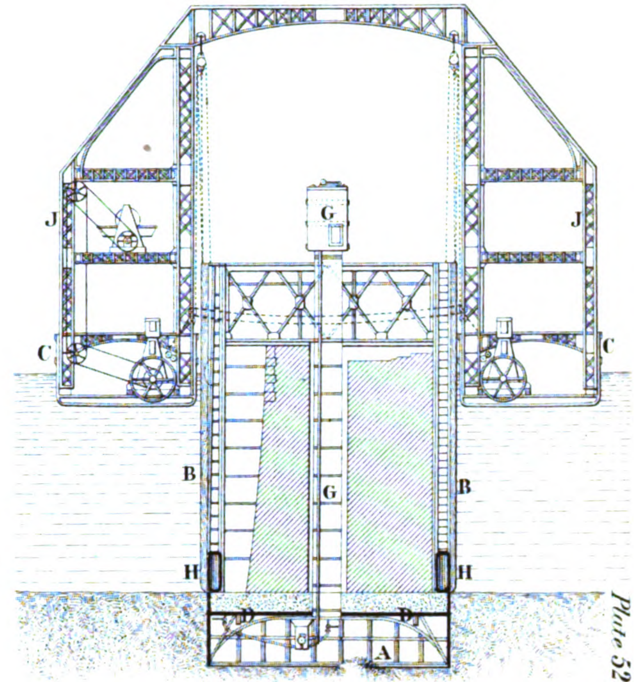


Fig. 4. Transverse Section.



Feet 10 5 0 10 20 30 40 50 60 70 80 Feet

Scale 1 to 300.

Plate 52.

LA GILEPPE DAM.

Fig. 1. Plan.
Scale 1 to 4000.

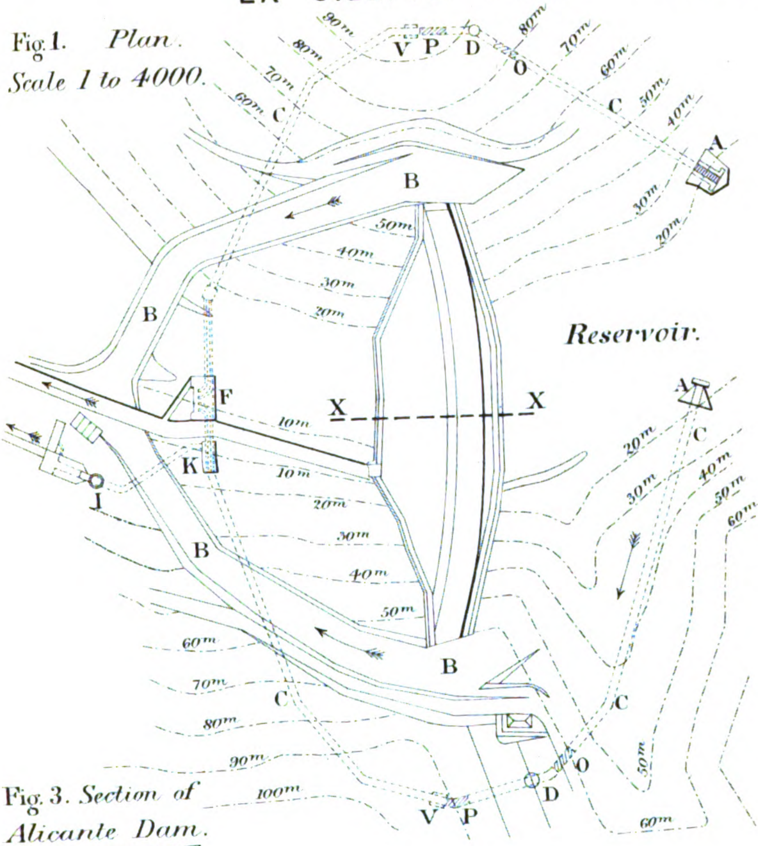


Fig. 3. Section of Alicante Dam.

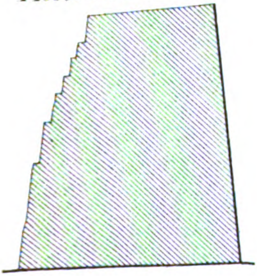


Fig. 4. Section of Furens Dam.

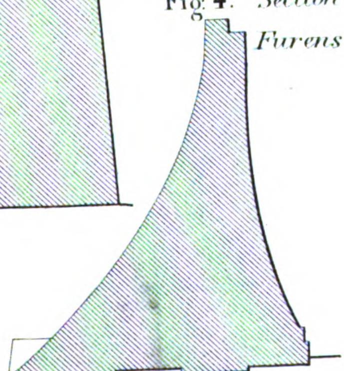
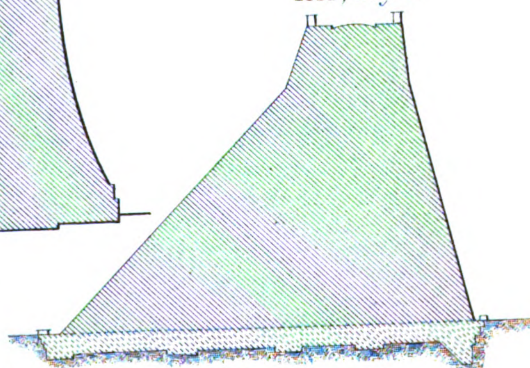


Fig. 2. Section at XX, Fig. 1.



Scale for Sections,
1 inch to 100 feet,
or 1 to 1200.

(Proceedings Inst. M.E. 1883.)

ENGINEE

AND BAS

Plate 54.

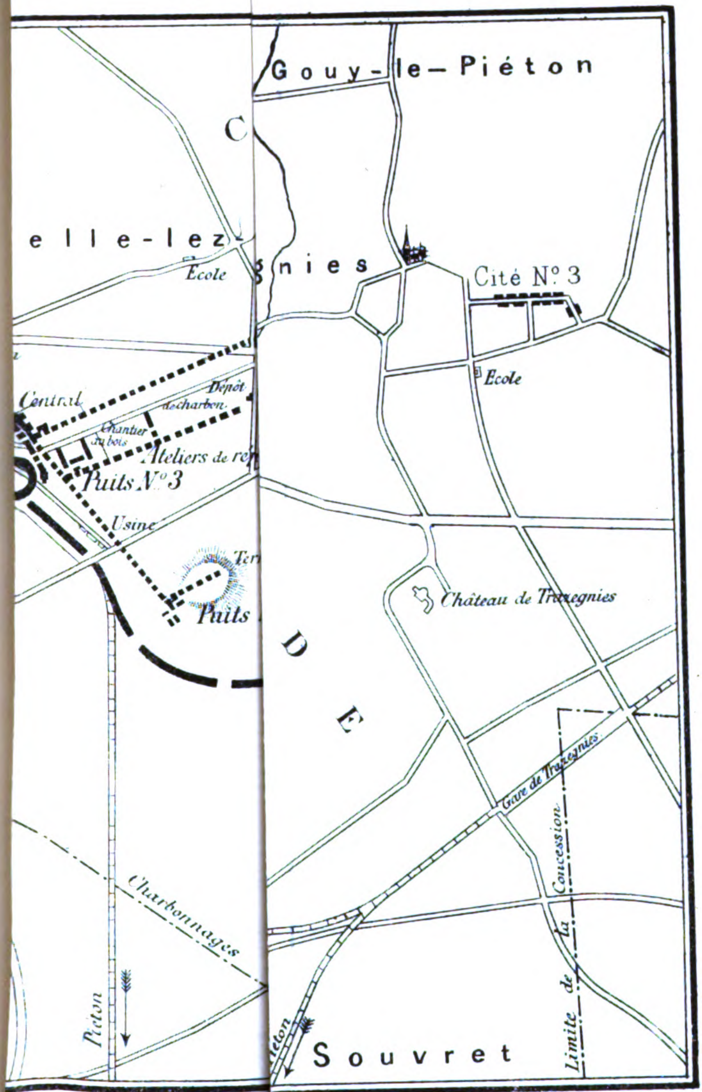
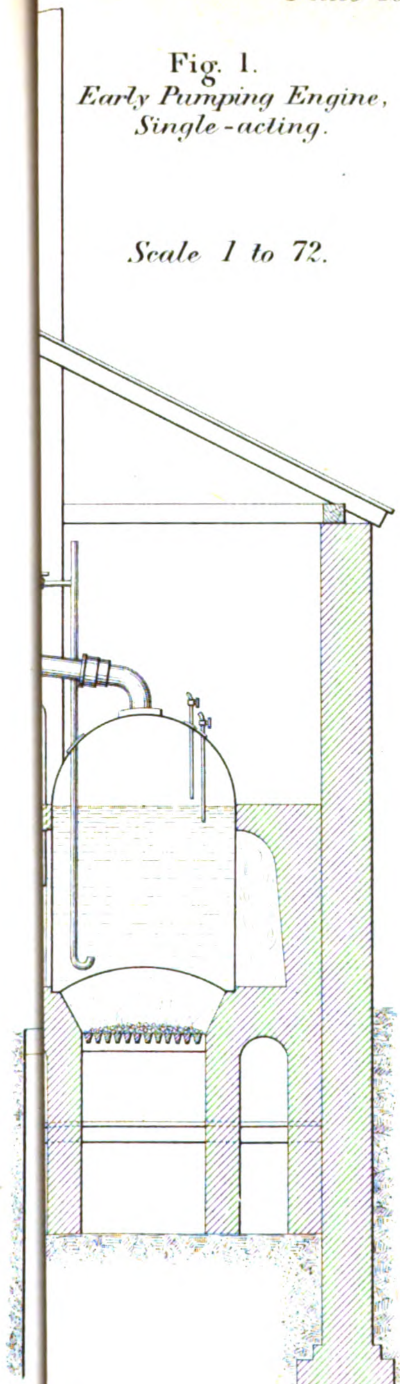


Fig. 1.
Early Pumping Engine,
Single-acting.

Scale 1 to 72.

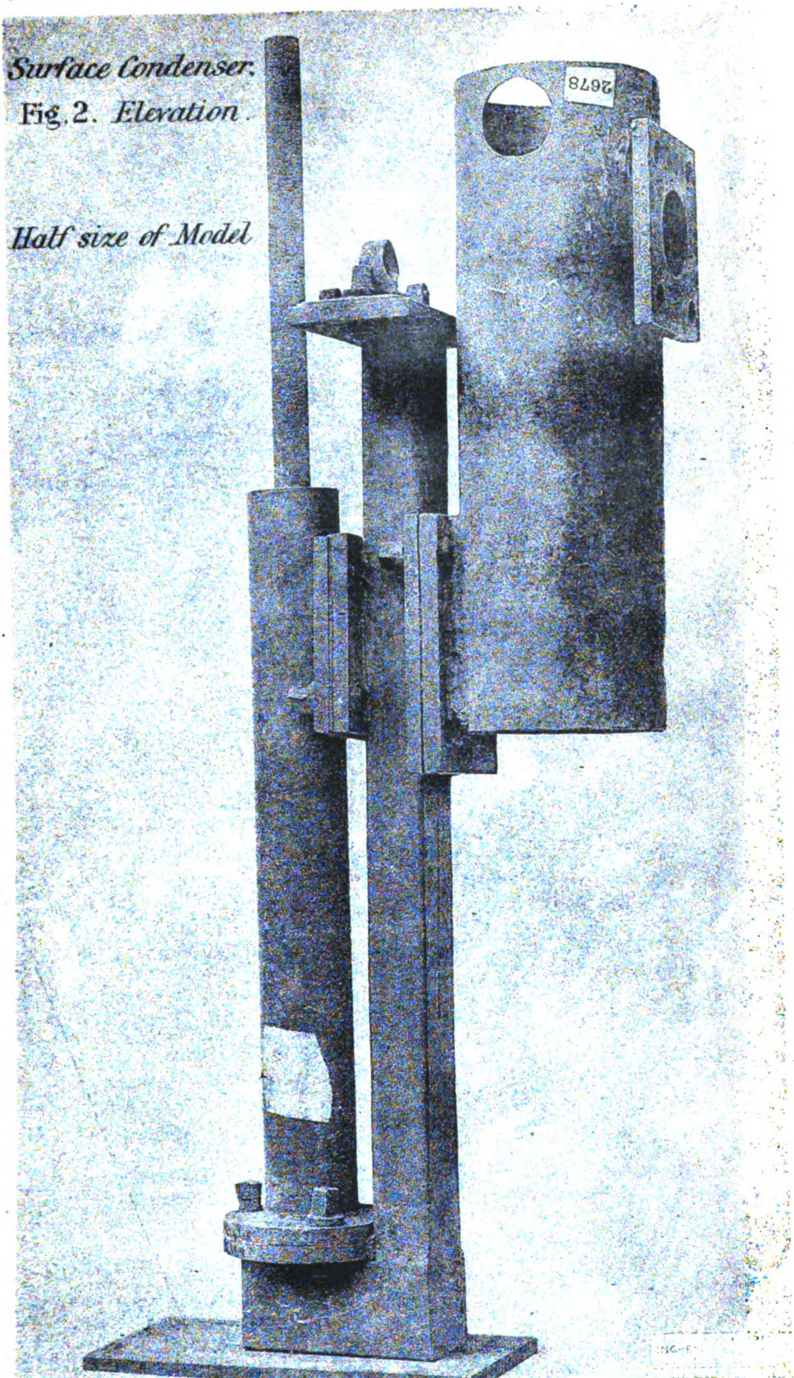


(Pr

Surface Condenser.

Fig. 2. *Elevation.*

Half size of Model



(Proceedings Inst. M.E. 1883.)

Surface Condenser.

Fig. 3. Section.

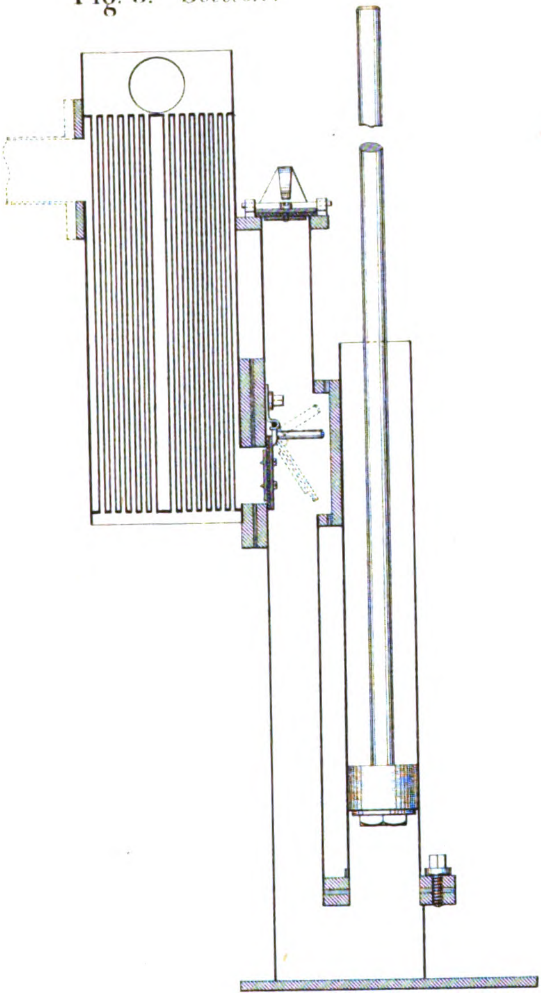
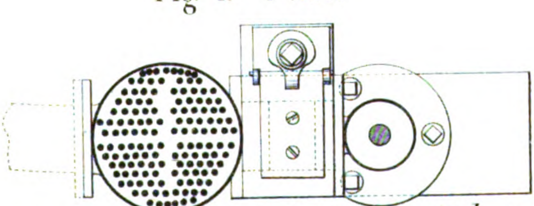


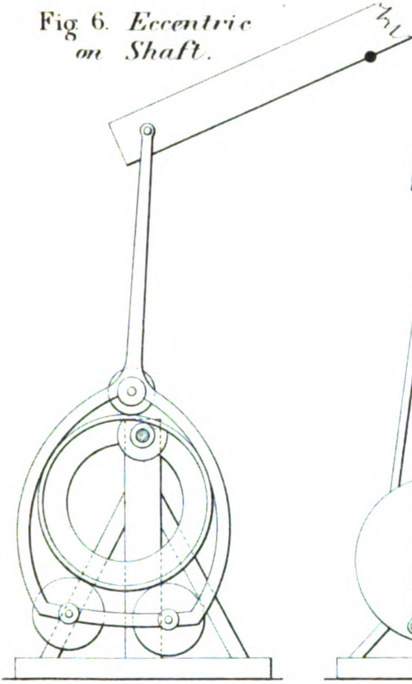
Fig. 4. Plan.



 1/3rd of Model.

Rotatory Motions.

Fig. 6. *Eccentric on Shaft.*



Discs with Crank-pins.

Fig. 5. *Elevation.*

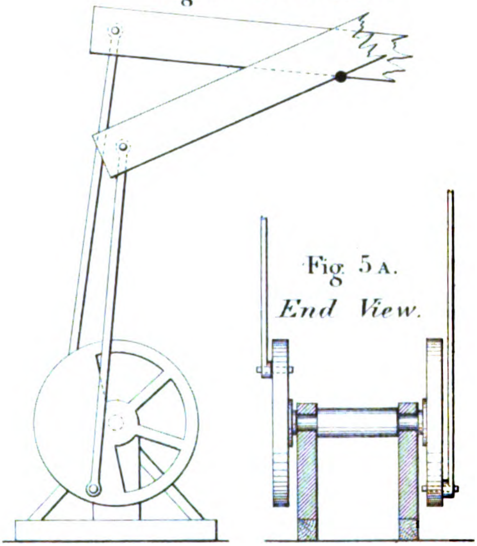


Fig. 5 A. *End View.*

Fig. 8. *Sun and Planet with internally geared rotating Disc.*

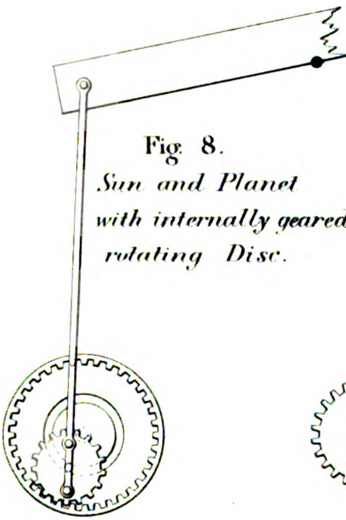
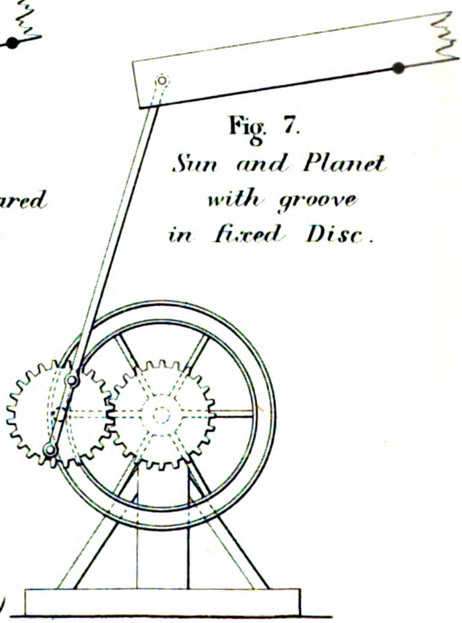


Fig. 7. *Sun and Planet with groove in fixed Disc.*



(Proceedings Inst. M. E. 1883.)

Model of Single-acting Engine, with balance-weight.

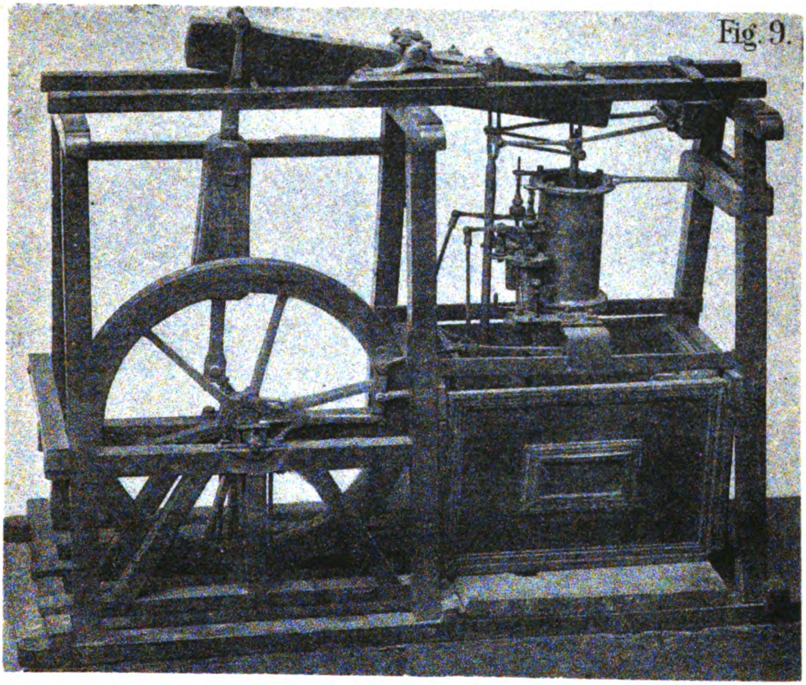


Fig. 9.

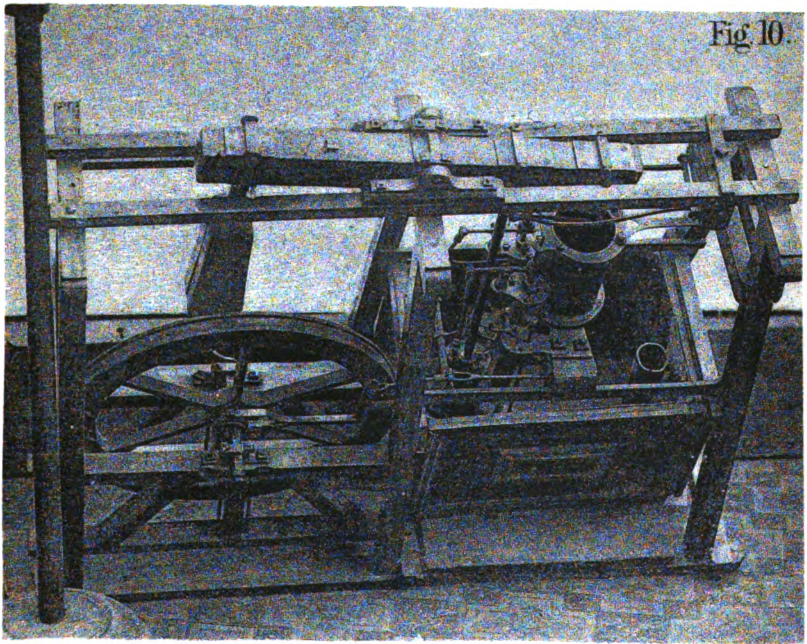


Fig. 10.

(Proceedings Inst. M.E. 1883.)

INVENTIONS OF WATT.

Sun and Planet Engine, Patent Office Museum.

Fig. 11. *Elevation.*

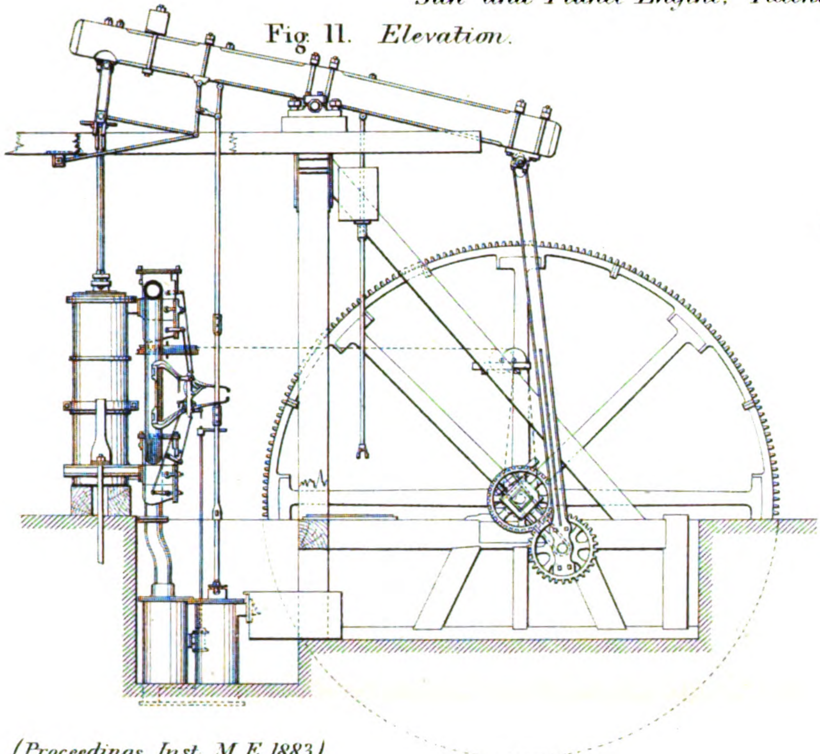
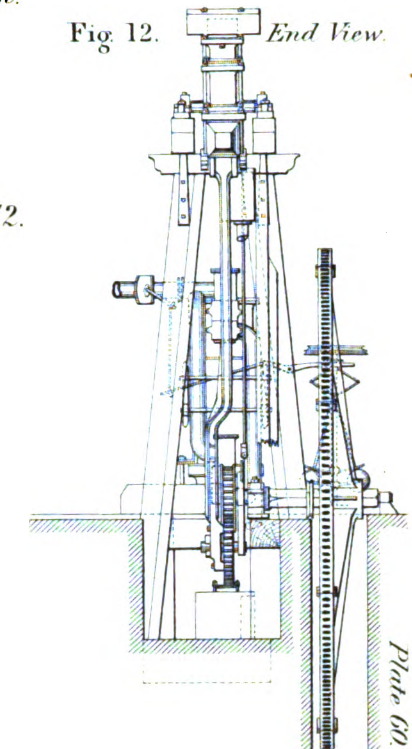


Fig. 12. *End View.*

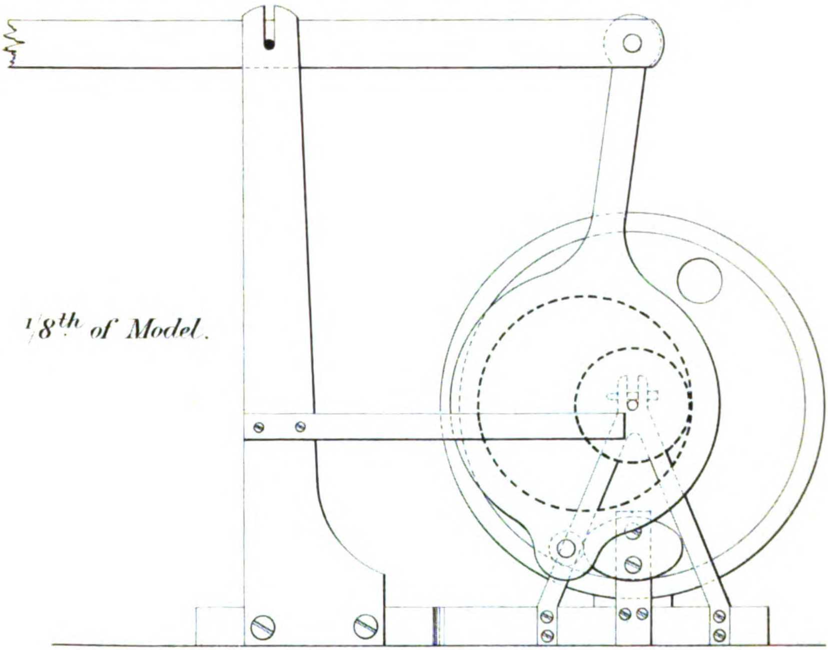


Scale 1 to 72.

Plate 60.

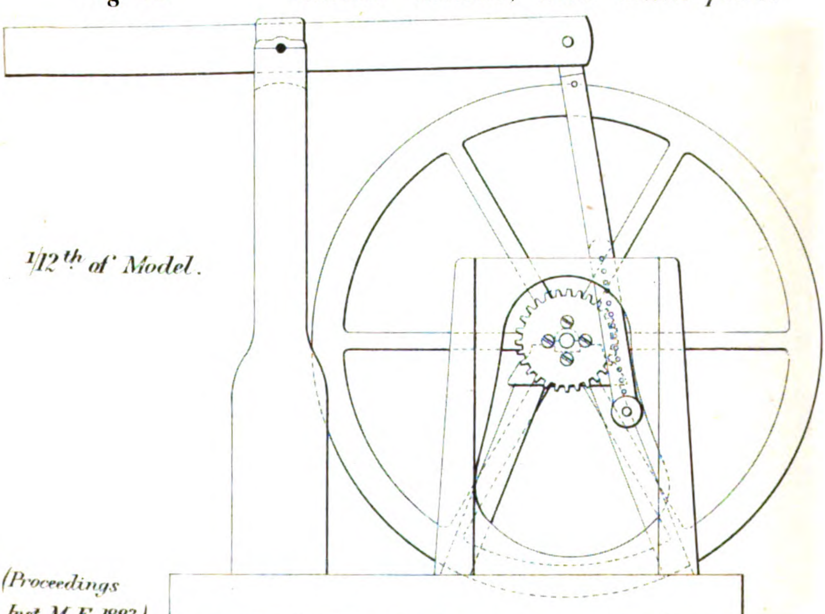
(Proceedings Inst. M. E. 1883.)

Fig. 13. *Rotatory Motion, with internal gear on Connecting-rod.*



1/8th of Model.

Fig. 14. *Ladder Motion, with Guide-plate.*



1/12th of Model.

(Proceedings Inst. M. E. 1883.)

Ladder Motion, with two Guide pins.

Fig. 16. *View showing Guides.*
1/3rd of Model.

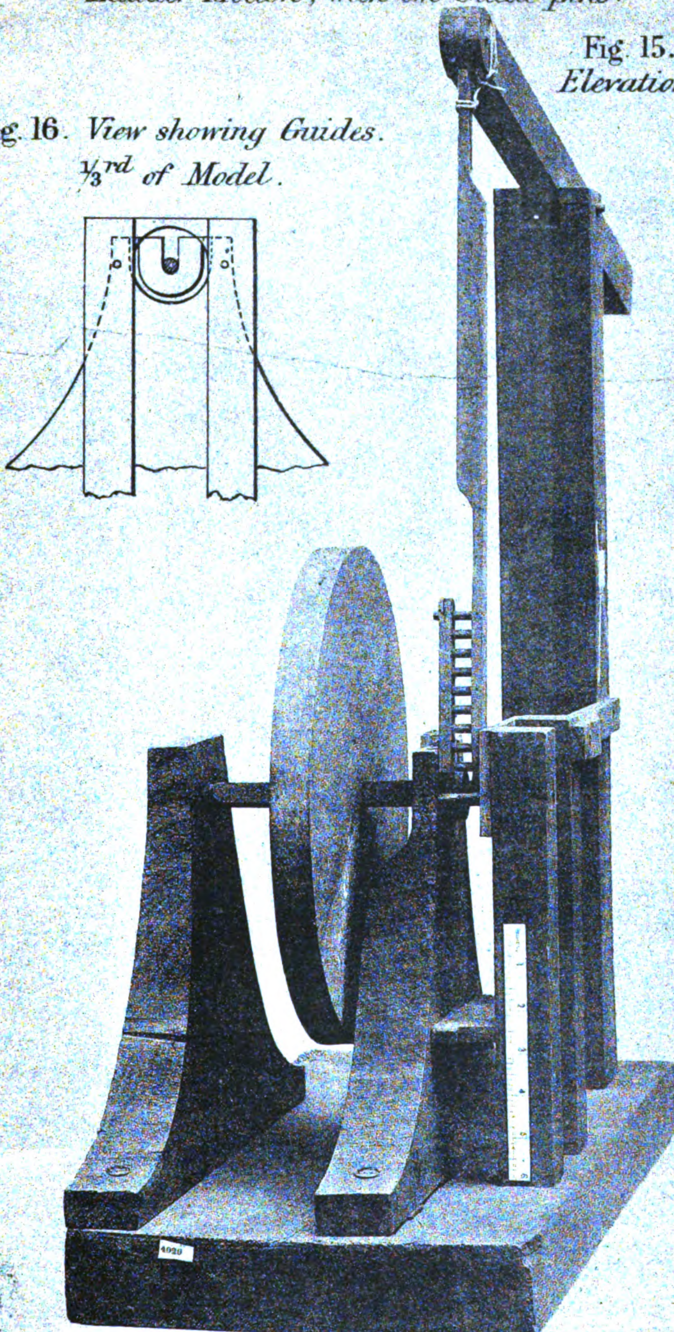


Fig. 15.
Elevation.

About 1/5th of Model.

(Proceedings Inst. M.E. 1883)

INVENTIONS OF WATT.

Winding Gear, with Crown Cam.

Fig. 17. *Side Elevation.*

$^1/_{8}$th *of Model.*

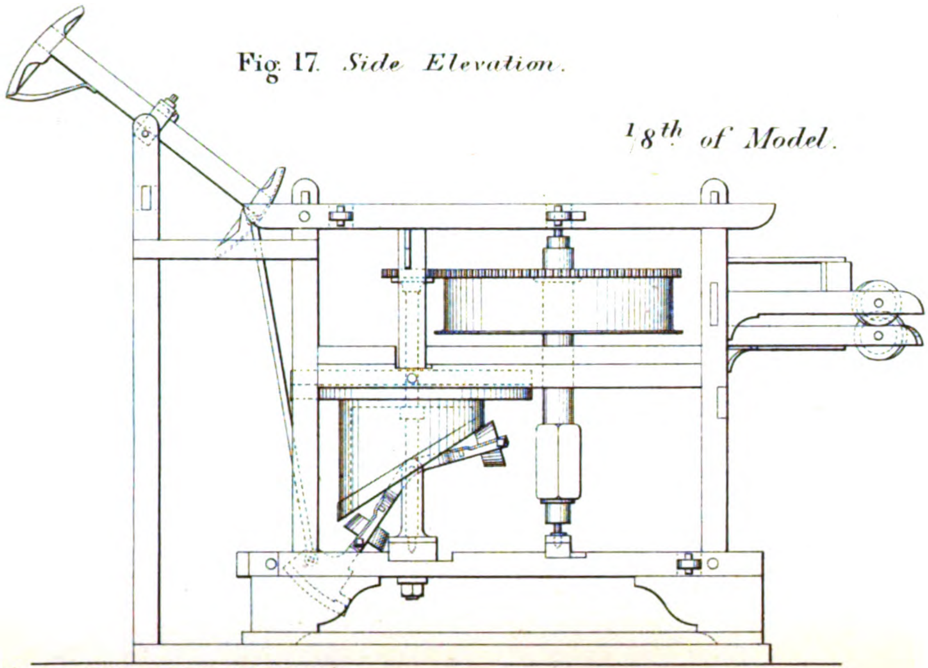


Fig. 18. *End Elevation.*

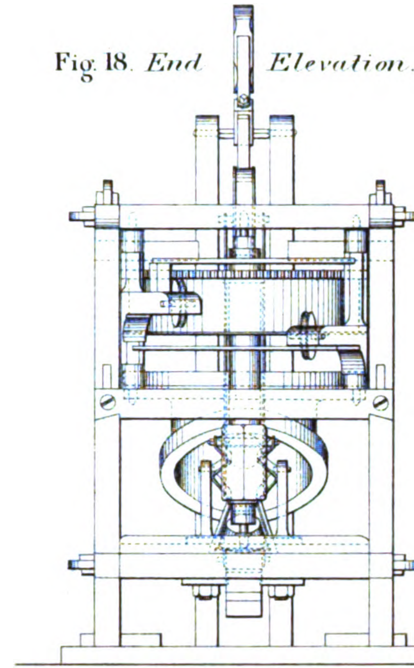
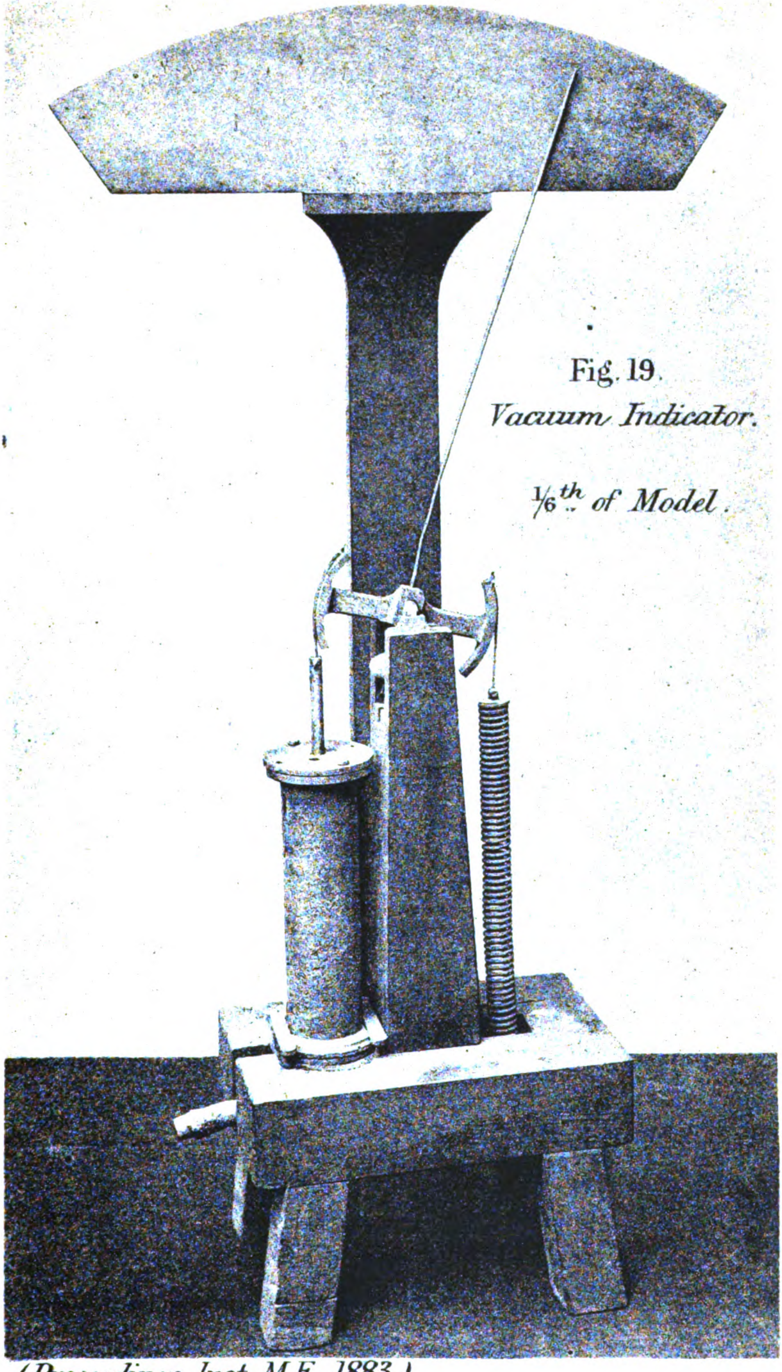


Plate 63.

(Proceedings Inst. M.E. 1883.)



(Proceedings Inst. M.E. 1883.)

Steam-Engine Indicator.

Fig. 20. Elevation.

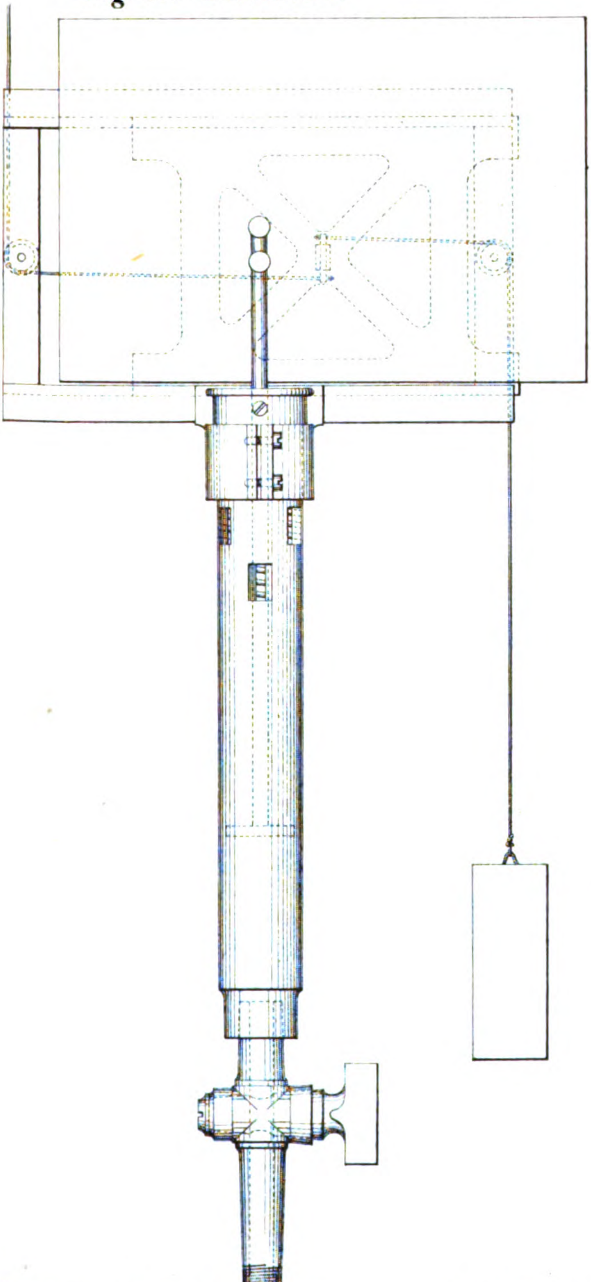
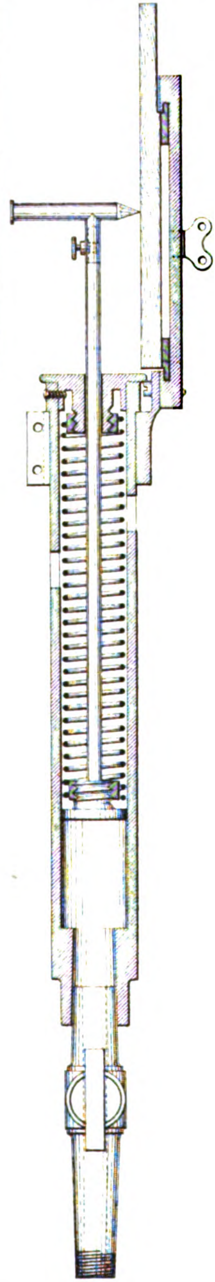


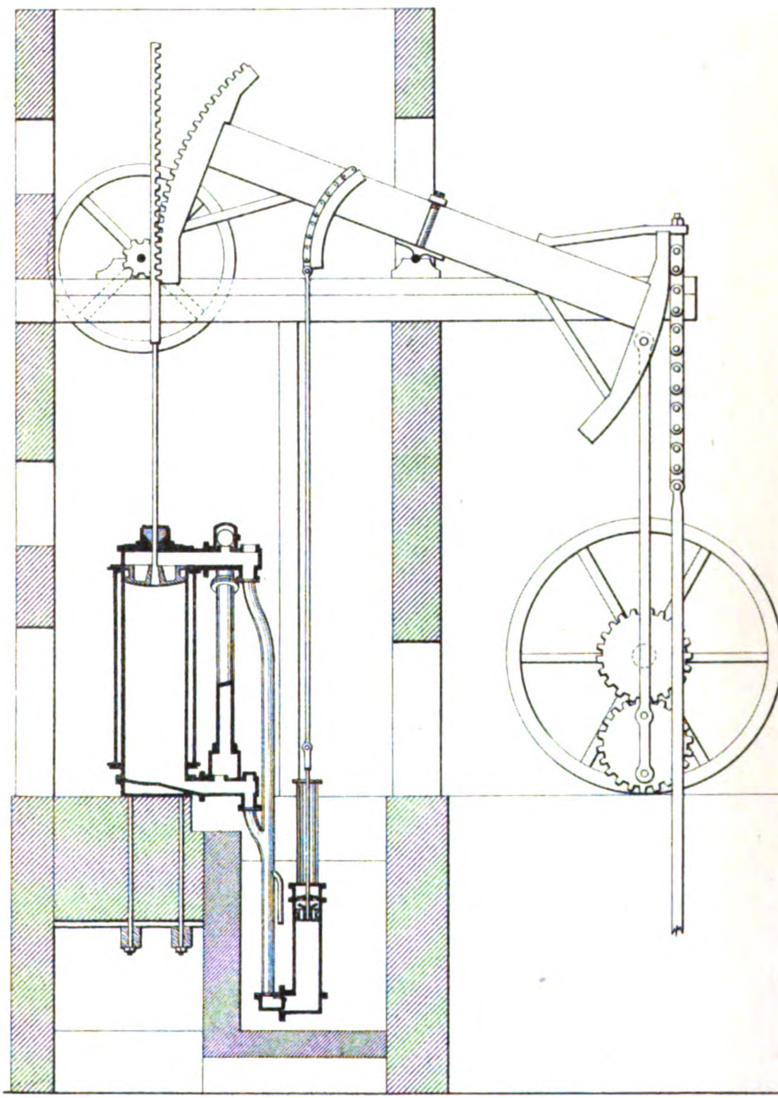
Fig. 21. Section.



(Proceedings Inst. M. E. 1883.)

Scale 1 to 3.

Fig. 22. *Balance-wheel Rotative Engine.*



(Proceedings Inst. M. E. 1883.) *Scale 1 to 96.*

Diagrams taken with Watt Indicator,
by Edward Cowper, Esq, August, 1840.

Fig. 23. *Full-Power Diagram.*

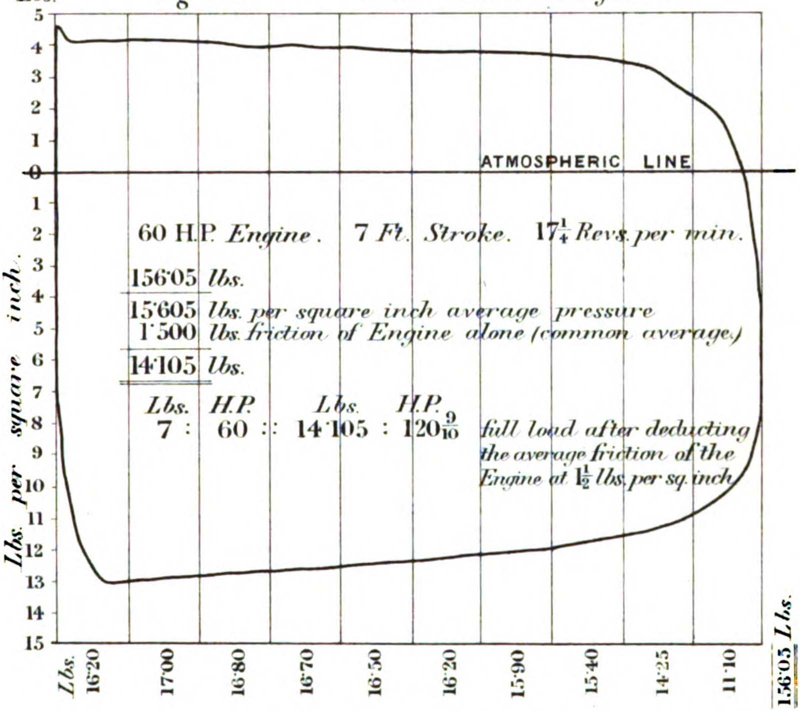
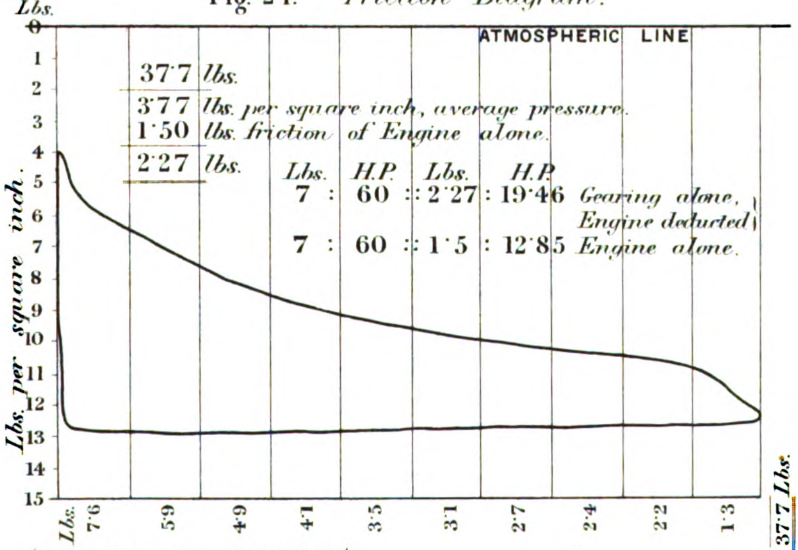
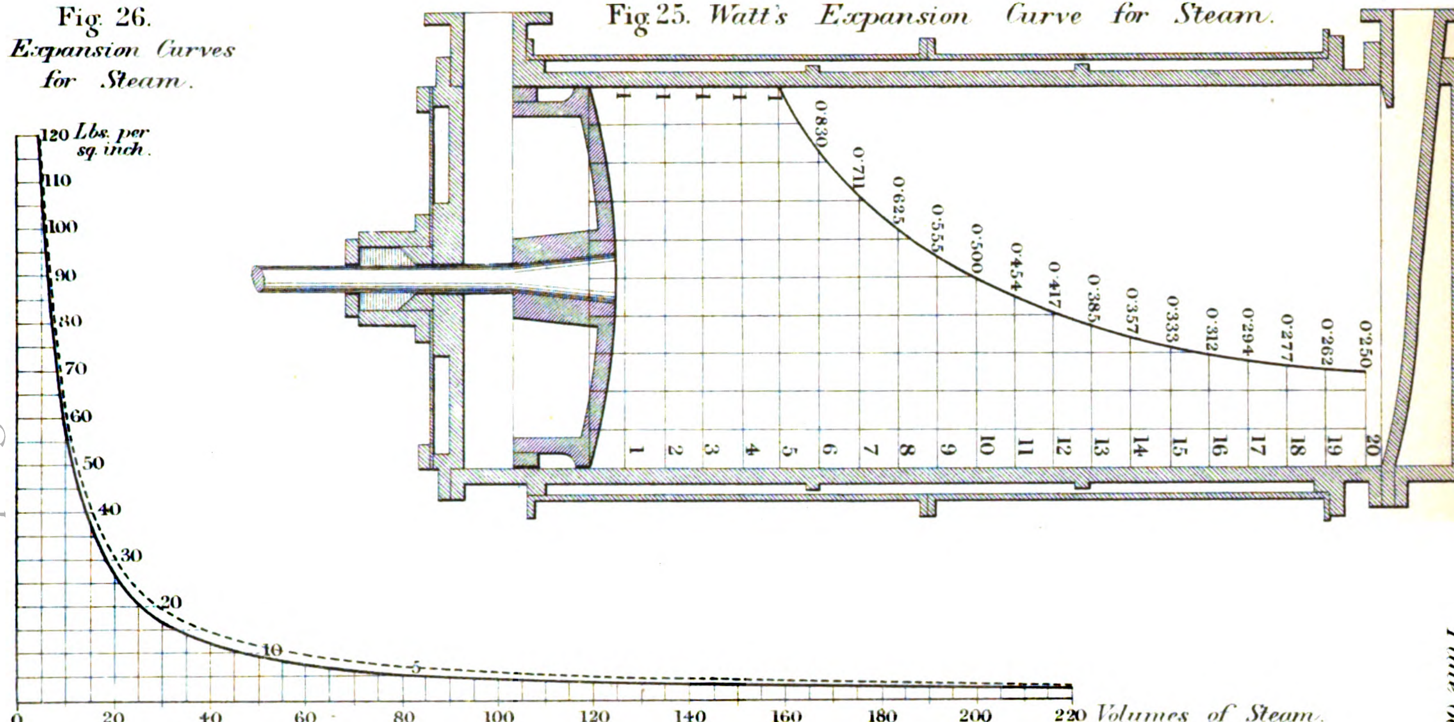


Fig. 24. *Friction Diagram.*



(Proceedings Inst. M. E. 1883.)

Fig. 26.
Expansion Curves for Steam.

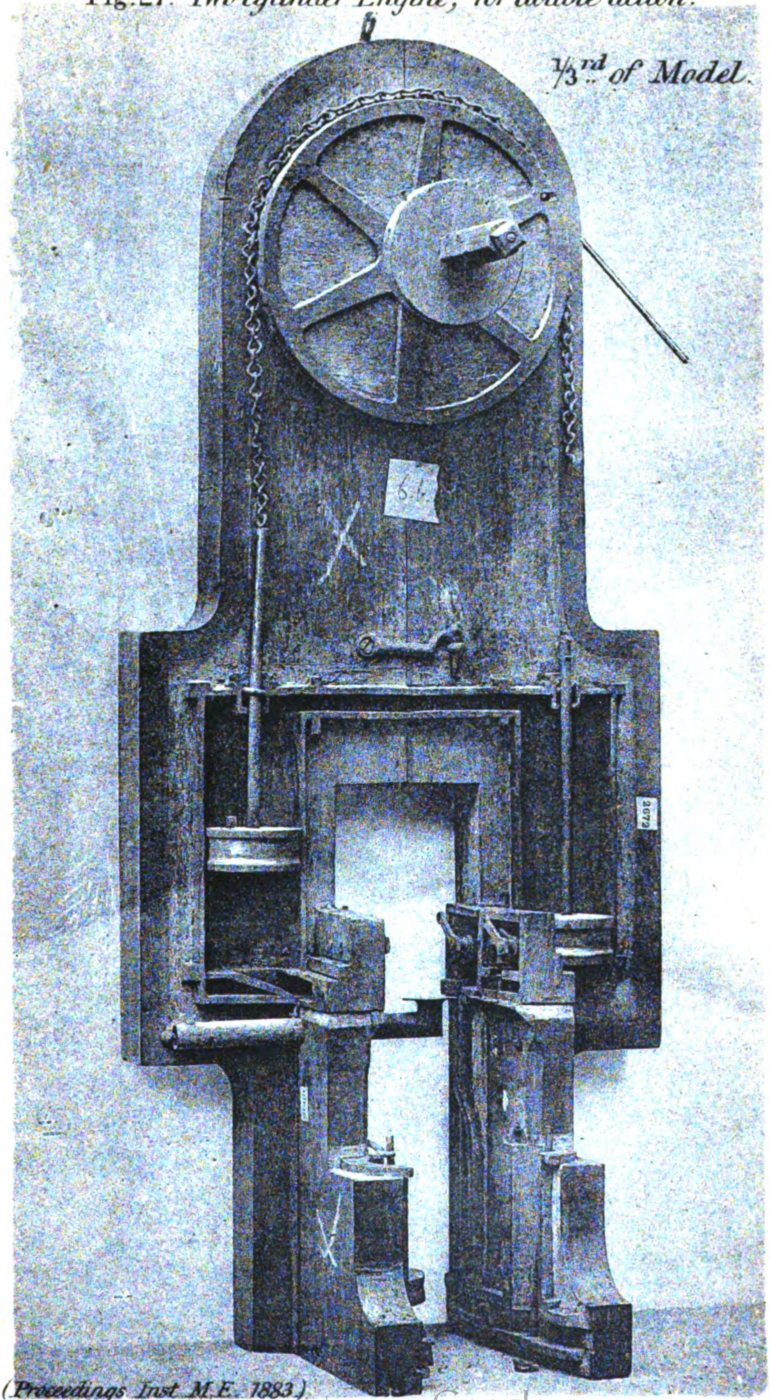


(Proceedings Inst. M.E. 1883.)

Fig. 25. *Watt's Expansion Curve for Steam.*

Plate 68.

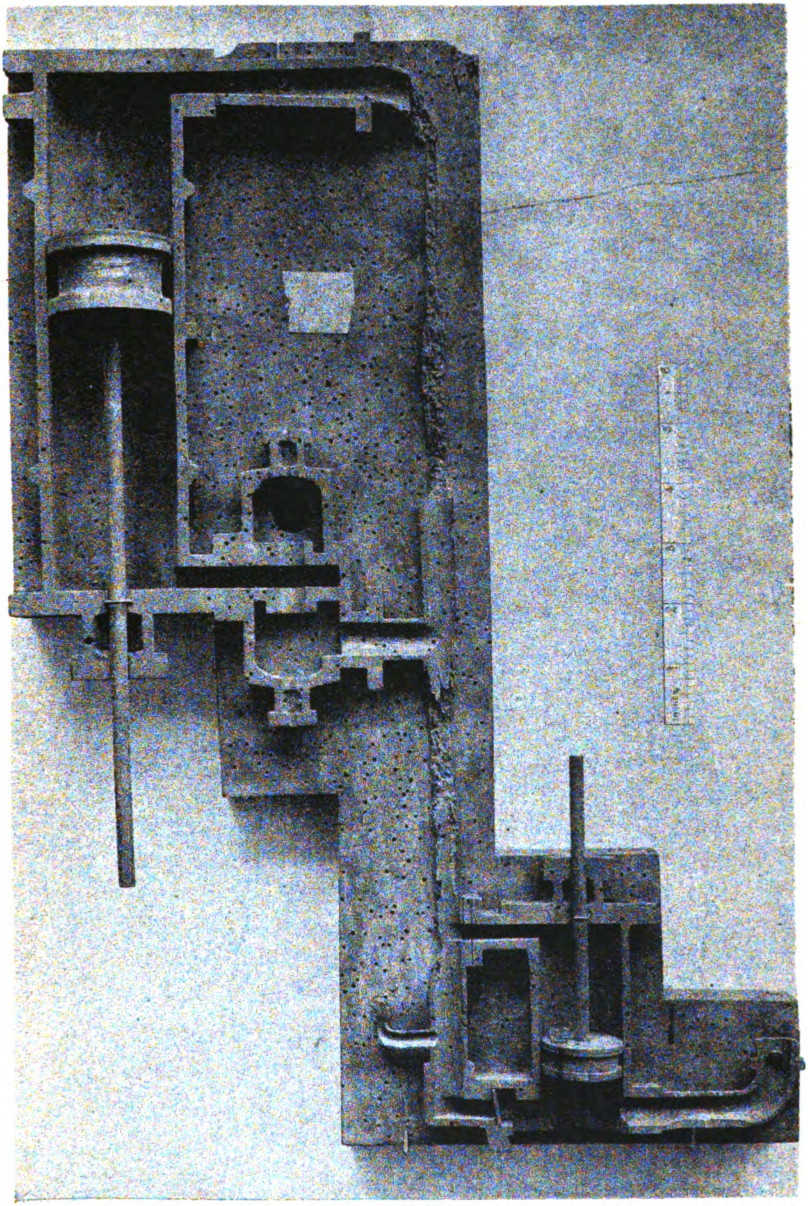
Fig. 27. *Two-cylinder Engine, for double action.*



(Proceedings Inst M.E. 1883.)

Bull Engine.

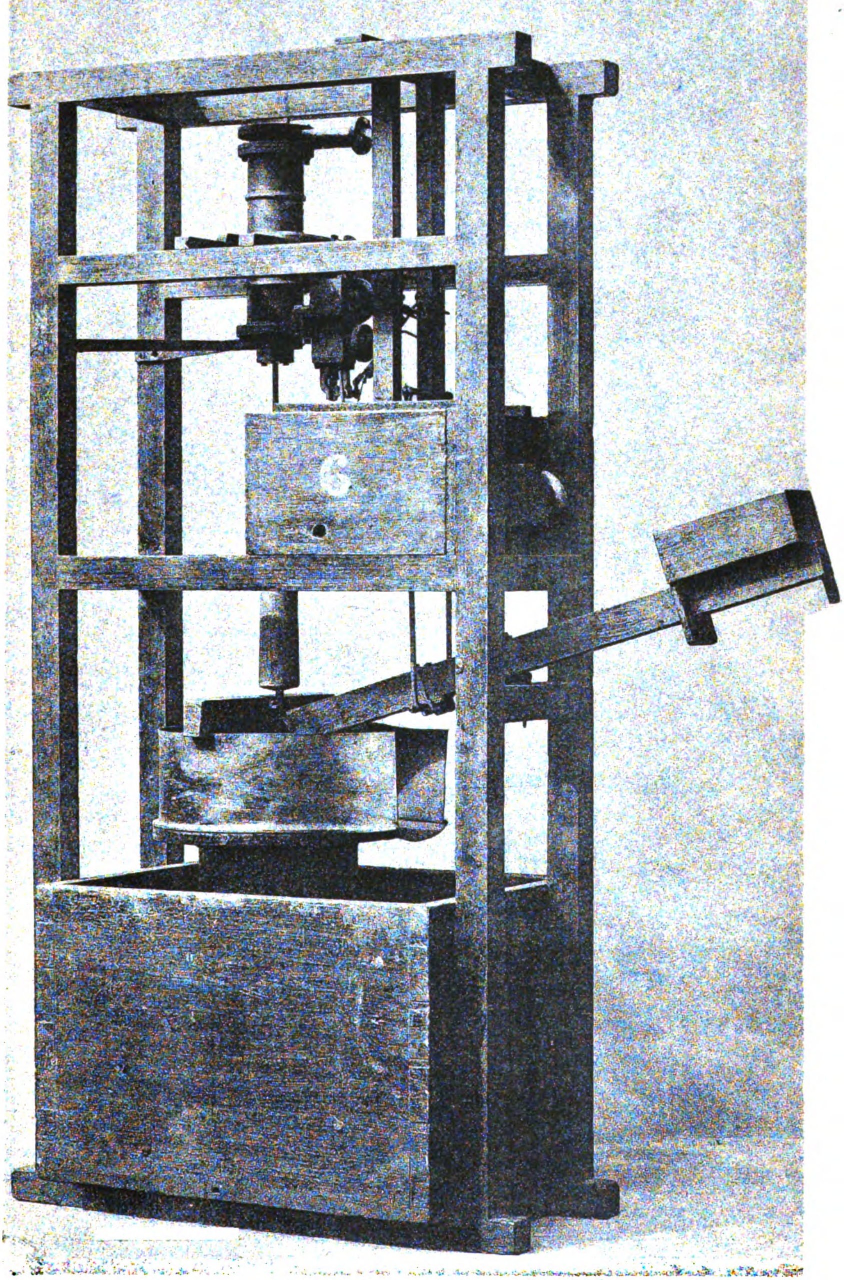
Fig. 28. *Sectional Model.*



(Proceedings Inst. M.E. 1883.) *About 1/3rd of Model.*

Bull Engine.

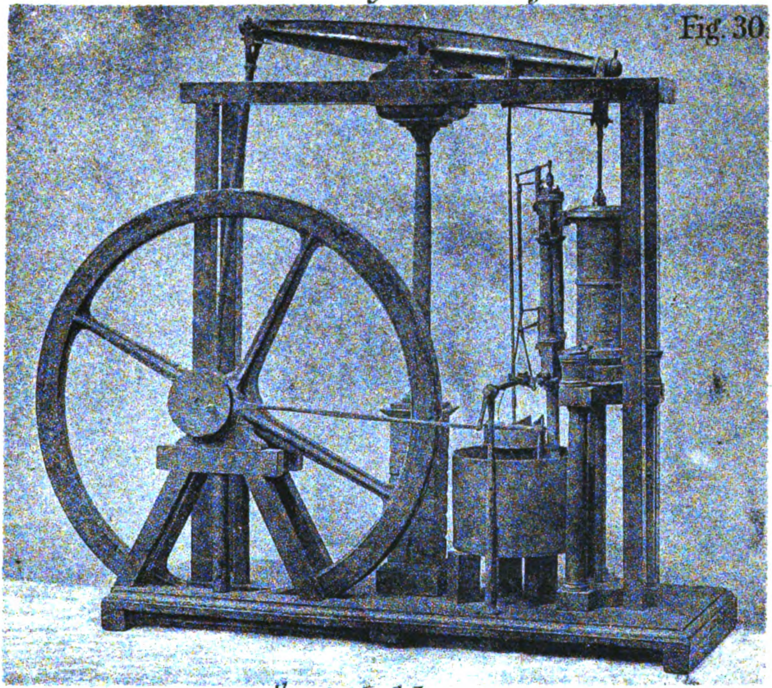
Fig. 29. General View.



(Proceedings Inst. M.E. 1883.) $\frac{1}{8}$th of Model.

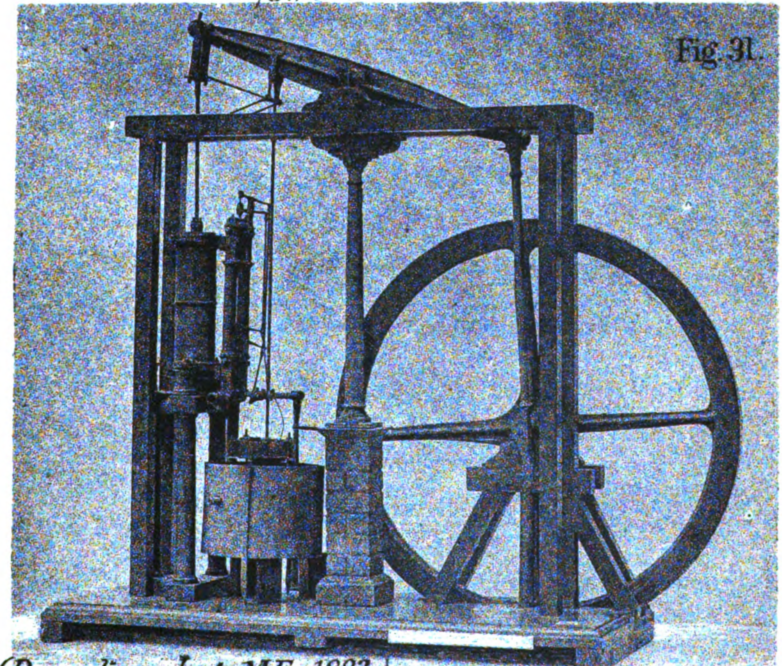
Double-acting Beam Engine.

Fig. 30.



1/8th of Model.

Fig. 31.



(Proceedings Inst M.E. 1883.)

INVENTIONS OF WATT.

Rolling and Slitting Mill.

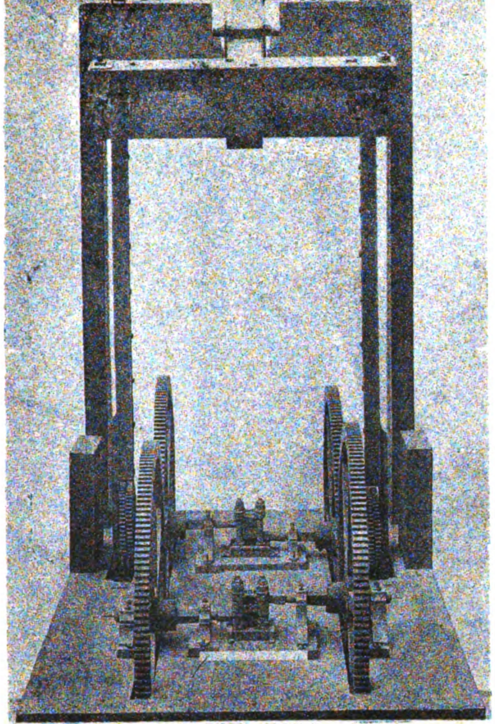


Fig. 32. End View.

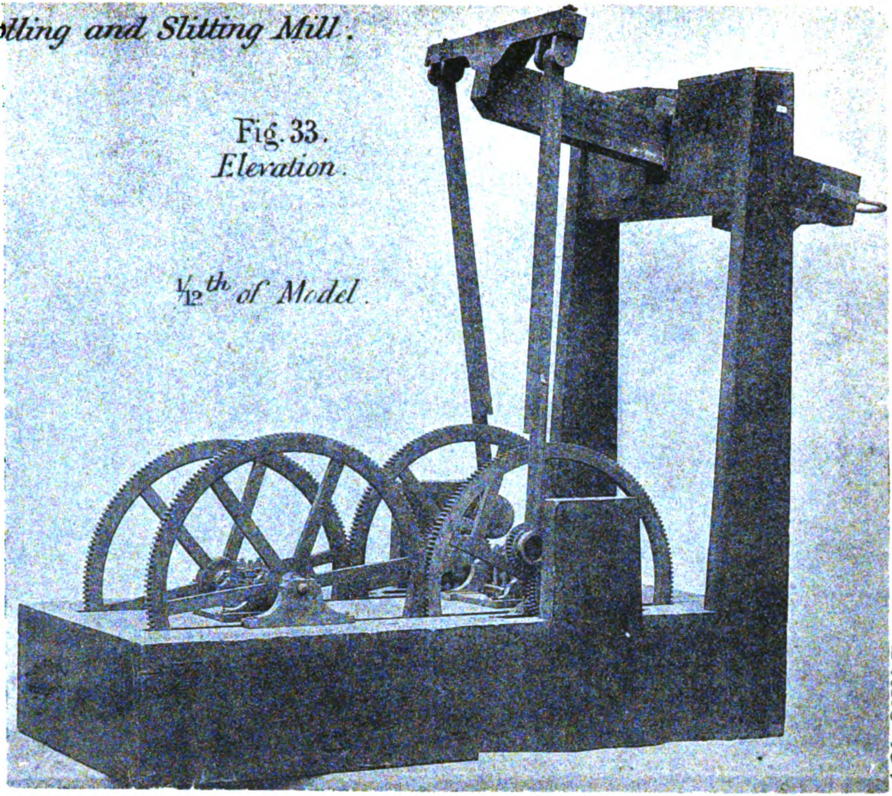


Fig. 33. Elevation.

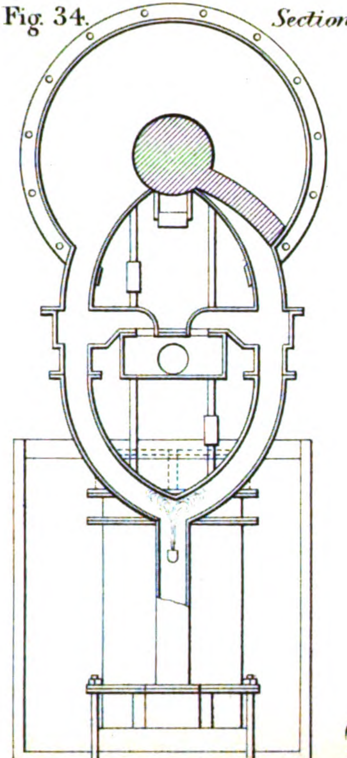
1/12th of Model.

(Proceedings Inst. M.E. 1883.)

Plate 73.

INVENTIONS OF WATT.

Fig. 34. Section.



Semi-rotary Engine.

Fig. 35. Side View.

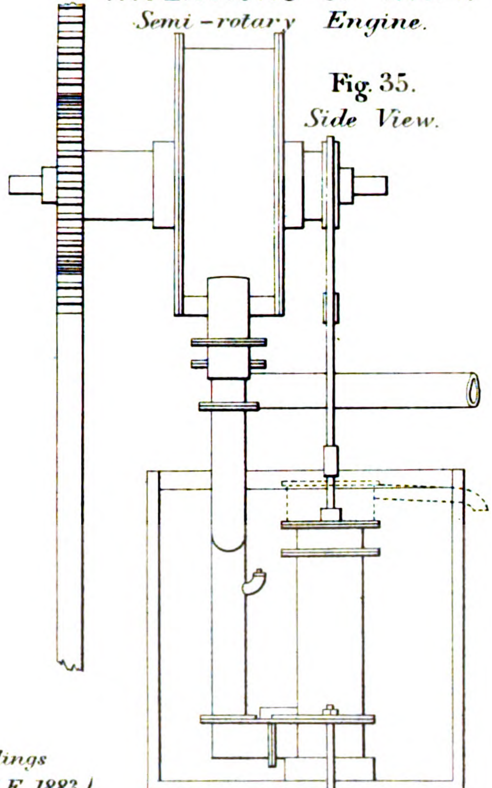


Fig. 36. Pump-rods & Pinion.

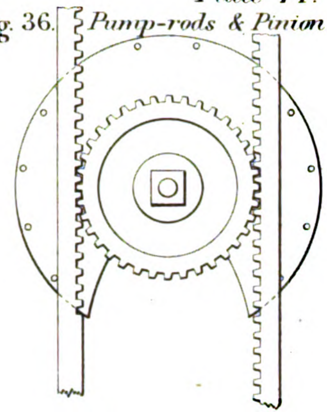
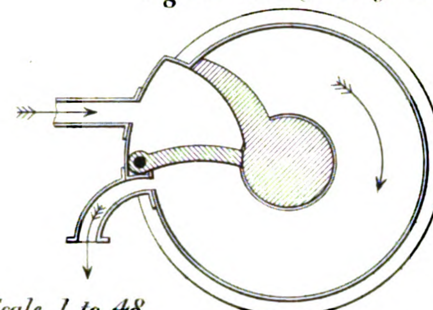


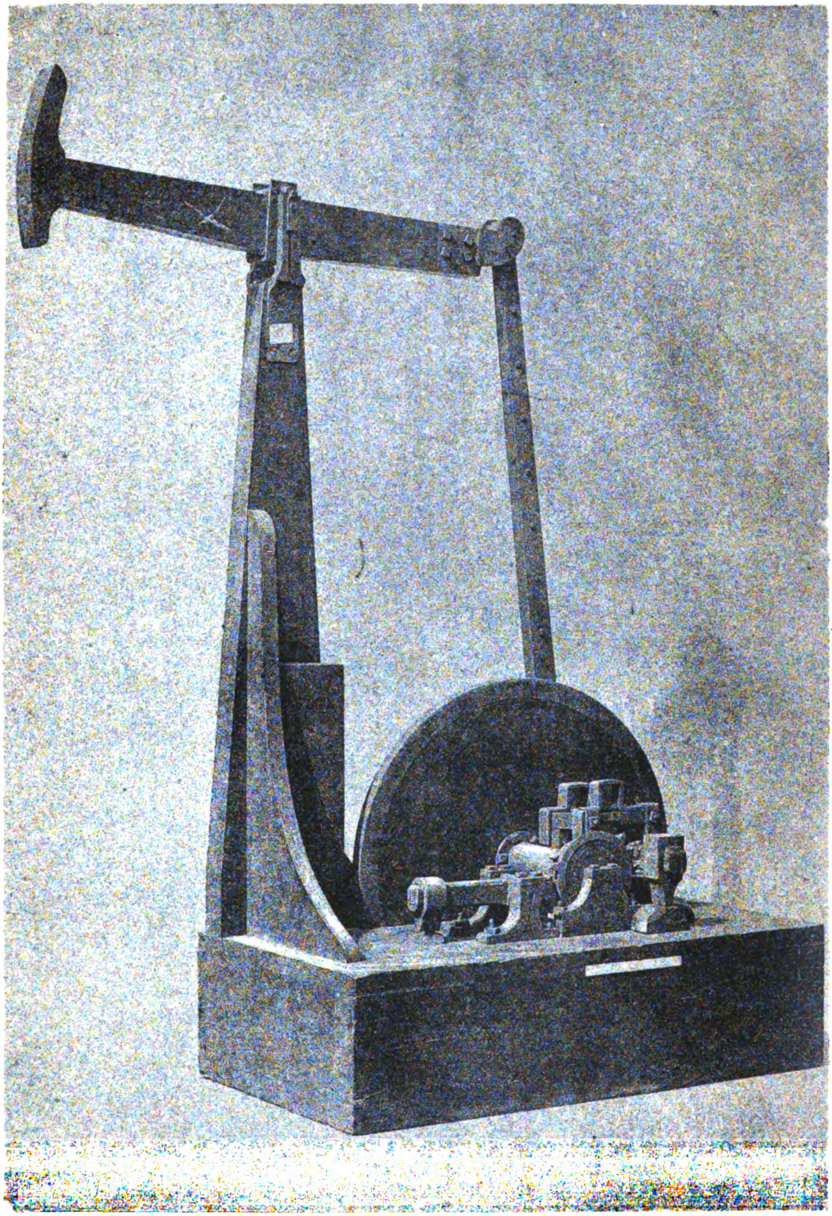
Fig. 37. Rotary Engine.



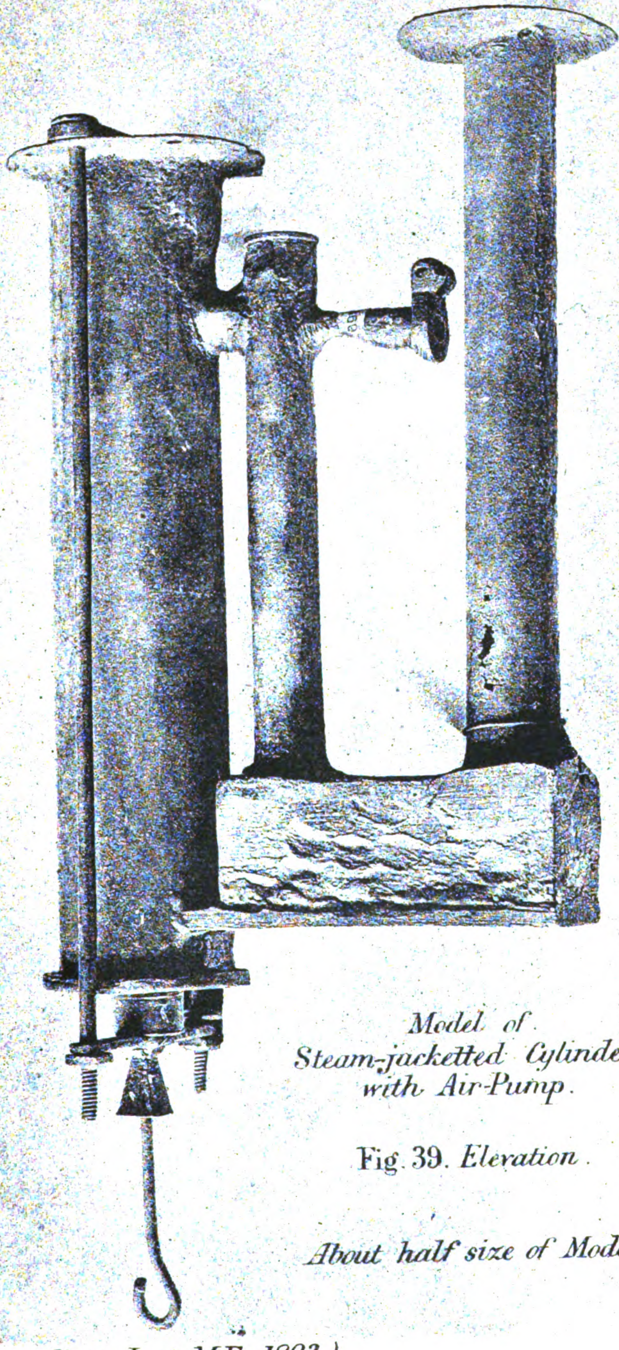
Scale 1 to 48.

(Proceedings Inst. M. E. 1883.)

Fig. 38. *Tilt Hammers.*



(Proceedings Inst. M.E. 1883.) *1/10th of Model.*

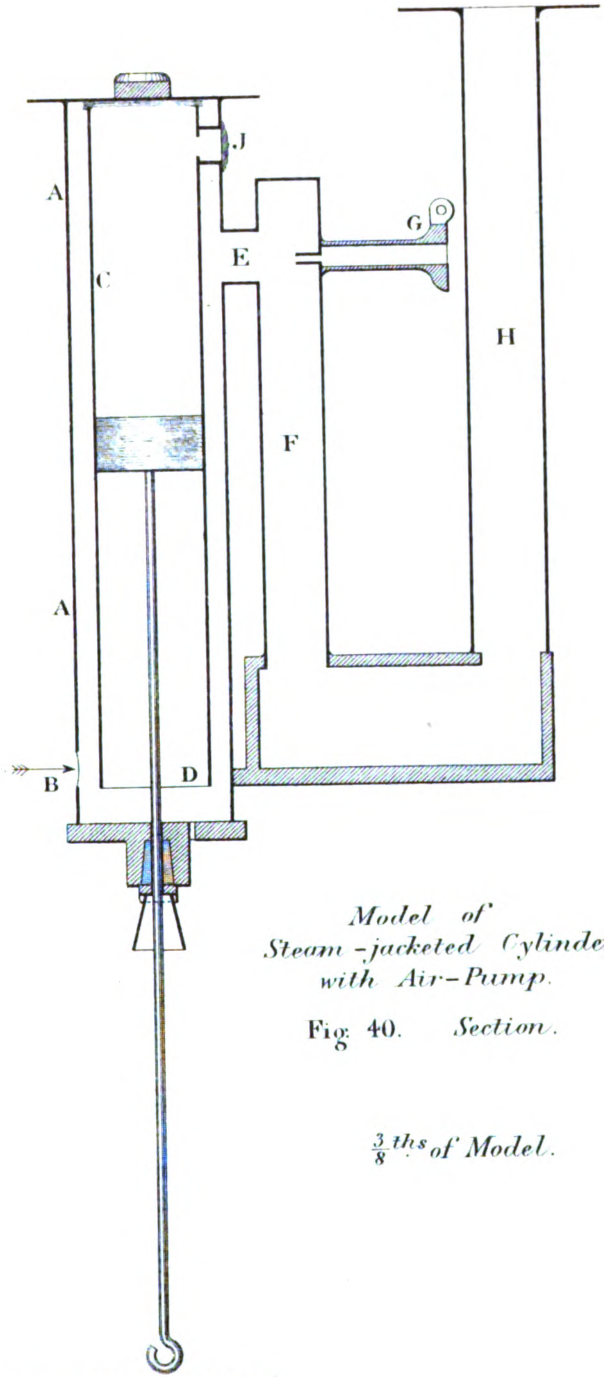


Model of Steam-jacketted Cylinder with Air-Pump.

Fig. 39. *Elevation.*

About half size of Model.

(Proceedings Inst. M.E. 1883.)



Model of Steam-jacketed Cylinder with Air-Pump.

Fig. 40. *Section.*

3/8ths of Model.

(Proceedings Inst. M. E. 1883.)

Fig. 41. *Intermittent Counter.*

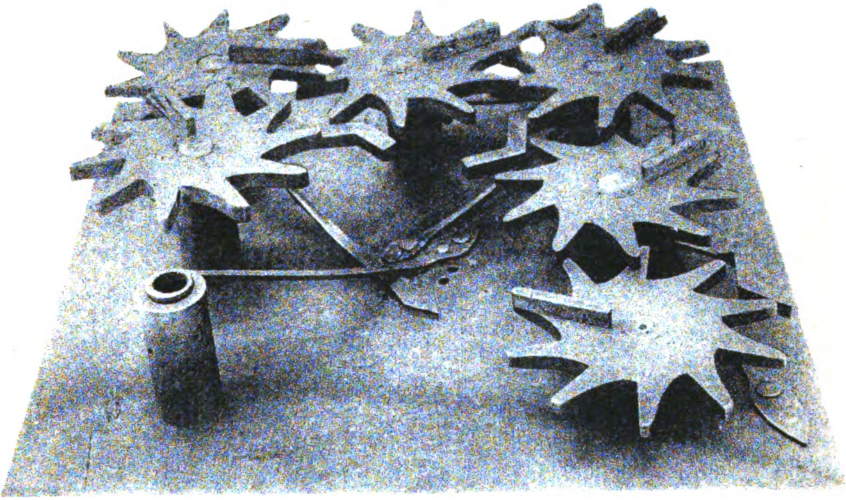
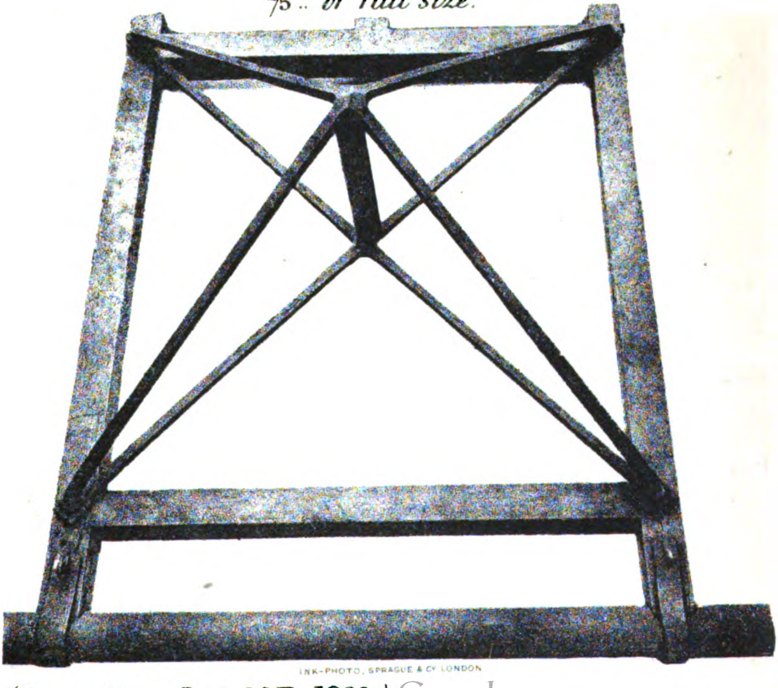


Fig. 42. *Trussed Frame for Copying Machine.*
1/5th of full size.



INVENTIONS OF WATT.

Geared Counter, Patent Office Museum.

Fig. 43. *Elevation.*

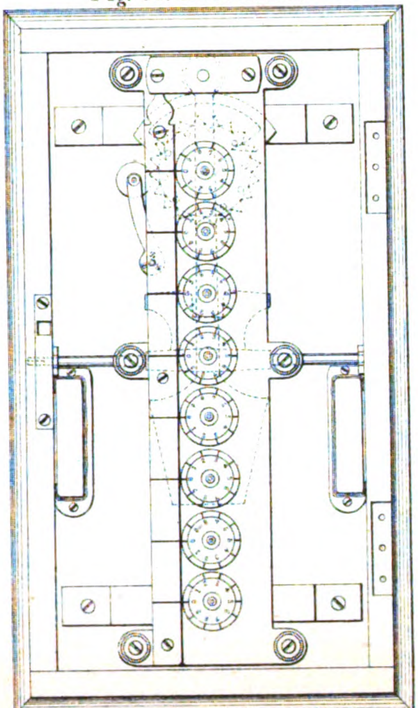


Fig. 44. *Side View.*

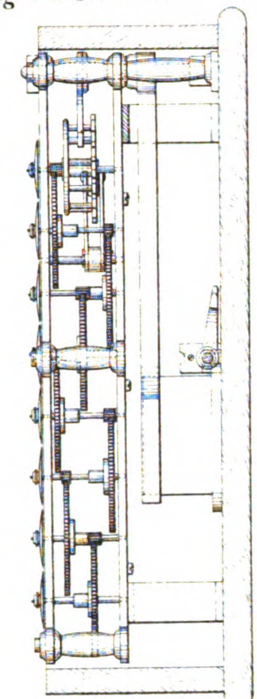


Fig. 45. *Arrangement of Gearing.*

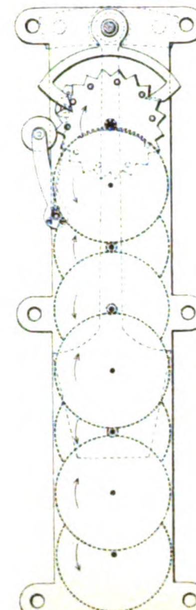


Fig. 46. *Case.*

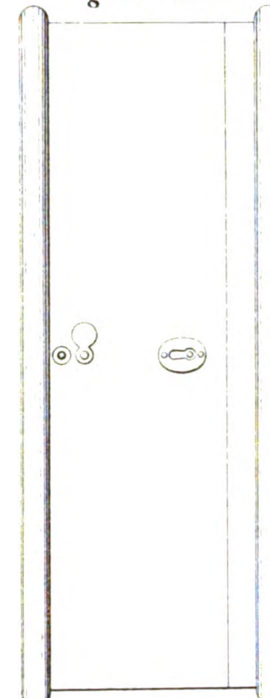


Plate 79.

Fig. 47. *Roller Copying-Press.*

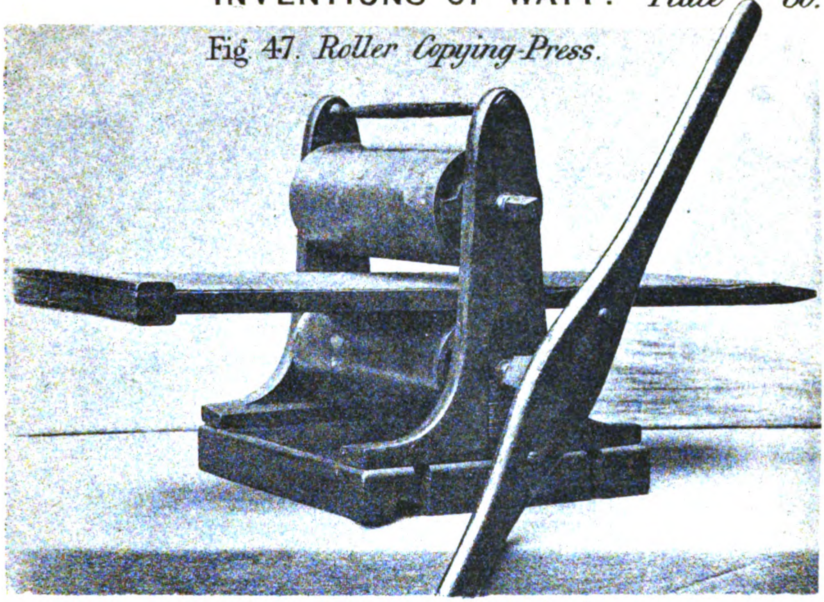


Fig. 48. *Cast of Face and Reduced Copy.*

(Proceedings Inst. M.E. 1883.)

Fig. 49. *Plan of Watt's Room, Heathfield Hall.*

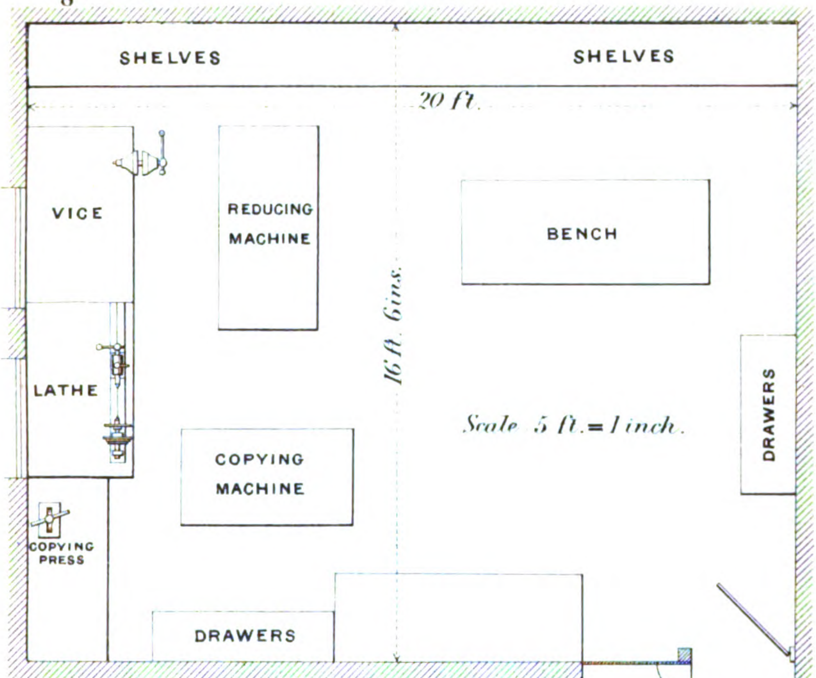


Fig. 50. *Folding Wedges.*

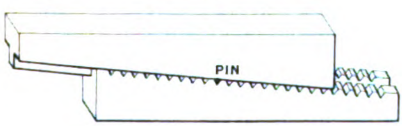
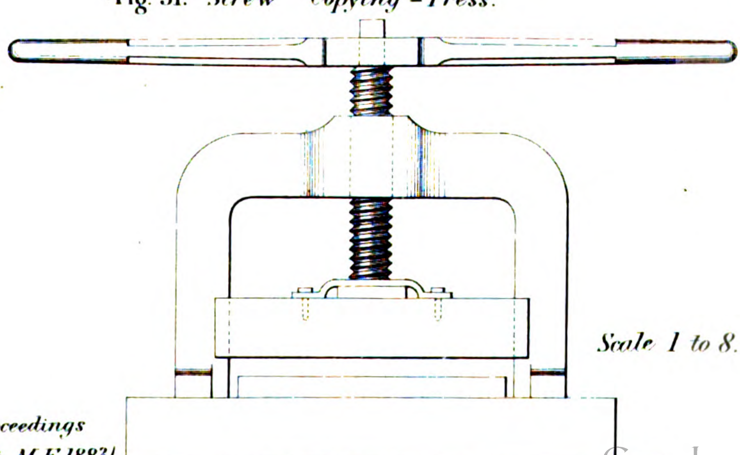


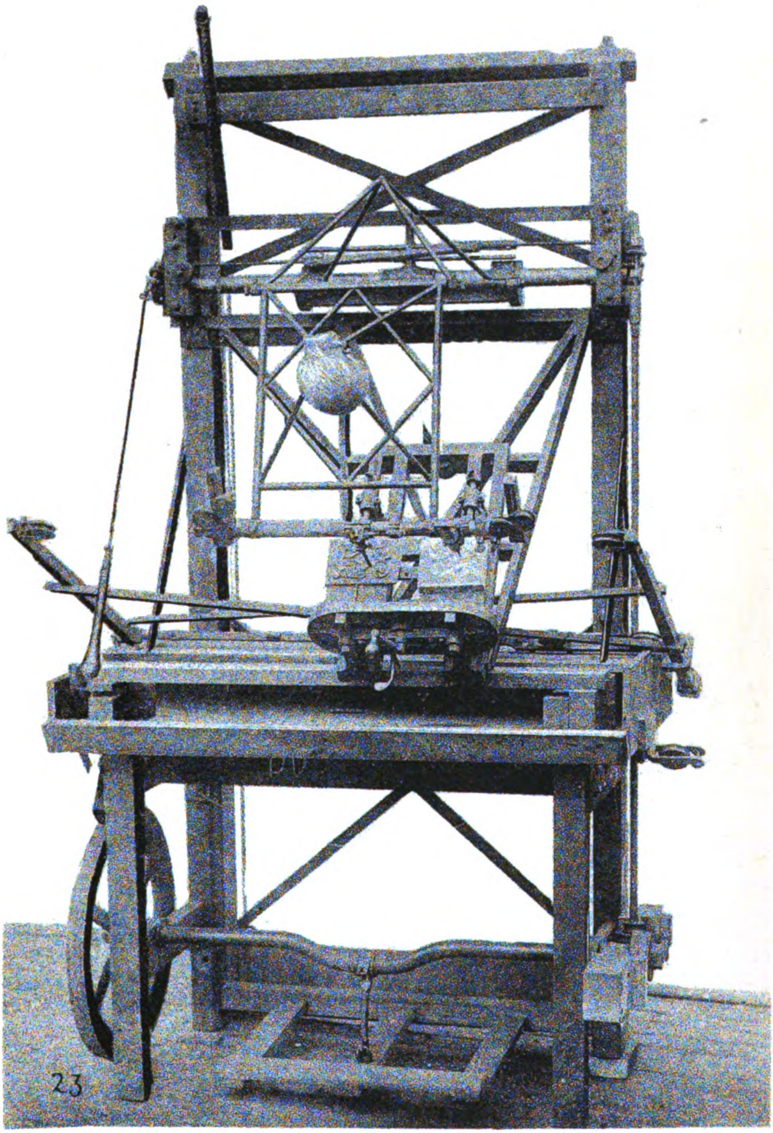
Fig. 51. *Screw Copying-Press.*



Scale 1 to 8.

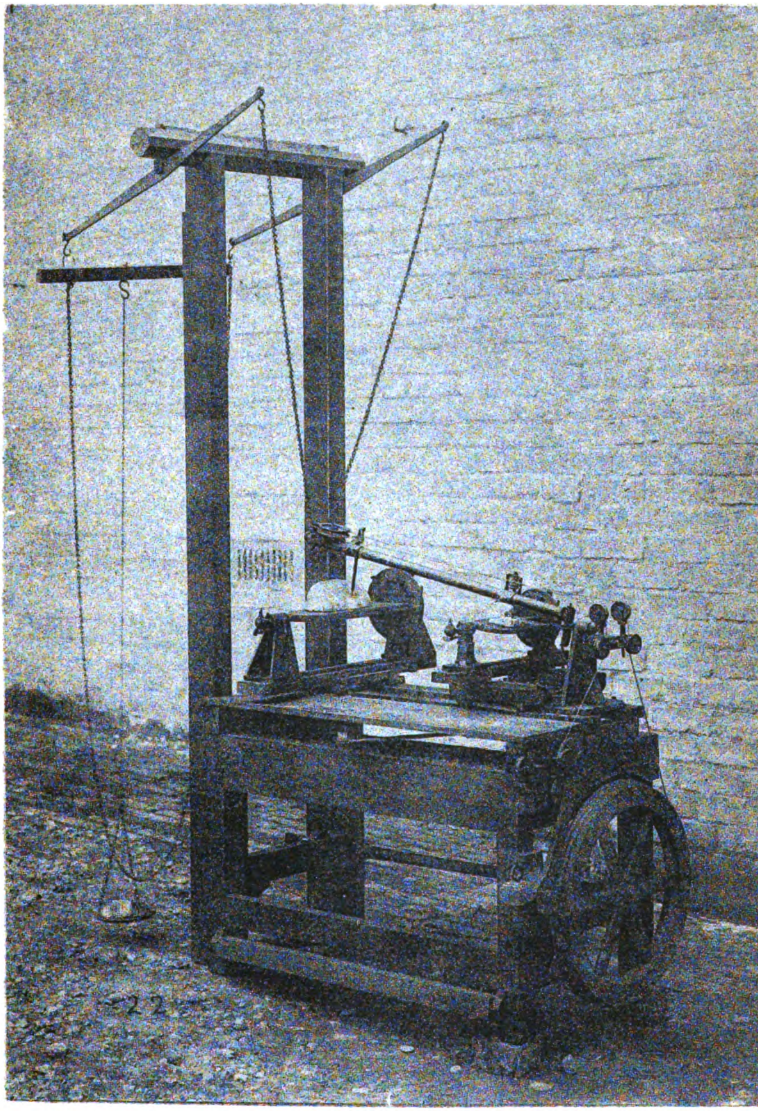
(Proceedings Inst. M. E. 1883).

Fig. 52. *Copying Machine for Sculpture.*



(Proceedings Inst. M.E. 1883.) *1/16th of full size.*

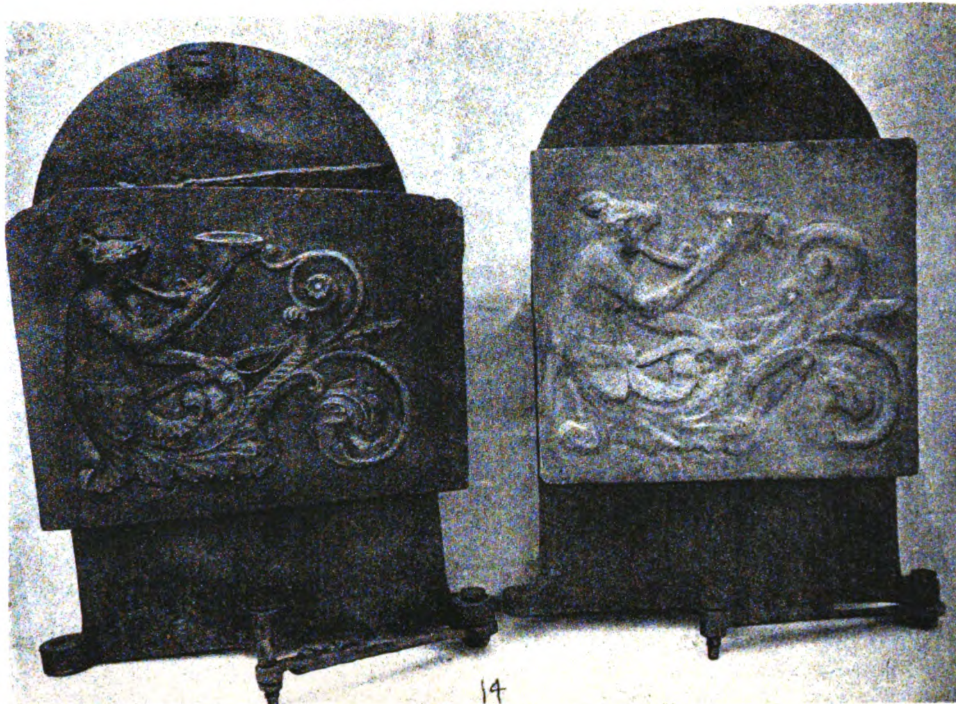
Fig. 53. *Reducing Machine for Sculpture.*



(Proceedings Inst. M.E. 1883.) *1/20th of full size.*

INVENTIONS OF WATT.

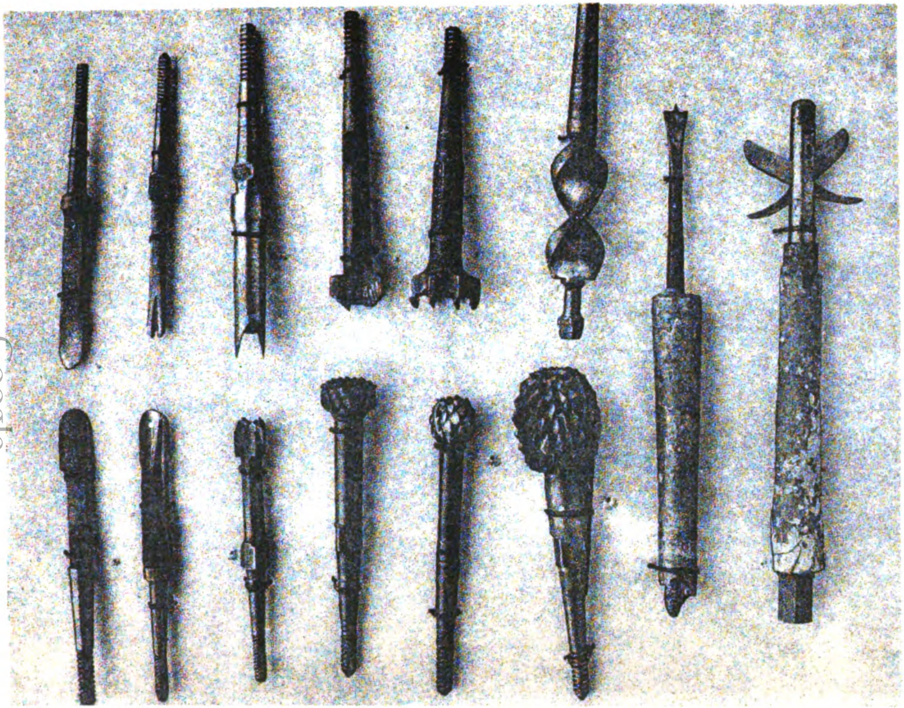
Fig 54 *Bas-relief and Copy*



(*Proceedings Inst. M.E. 1883.*)

Plate 84.

Fig. 55. *Tools for Sculpturing Machines.*



(*Proceedings Inst. M.E. 1883.*)

Fig. 56. *Unfinished Bust. Reducing Machine.*

Plate 86.

INVENTIONS OF WATT.

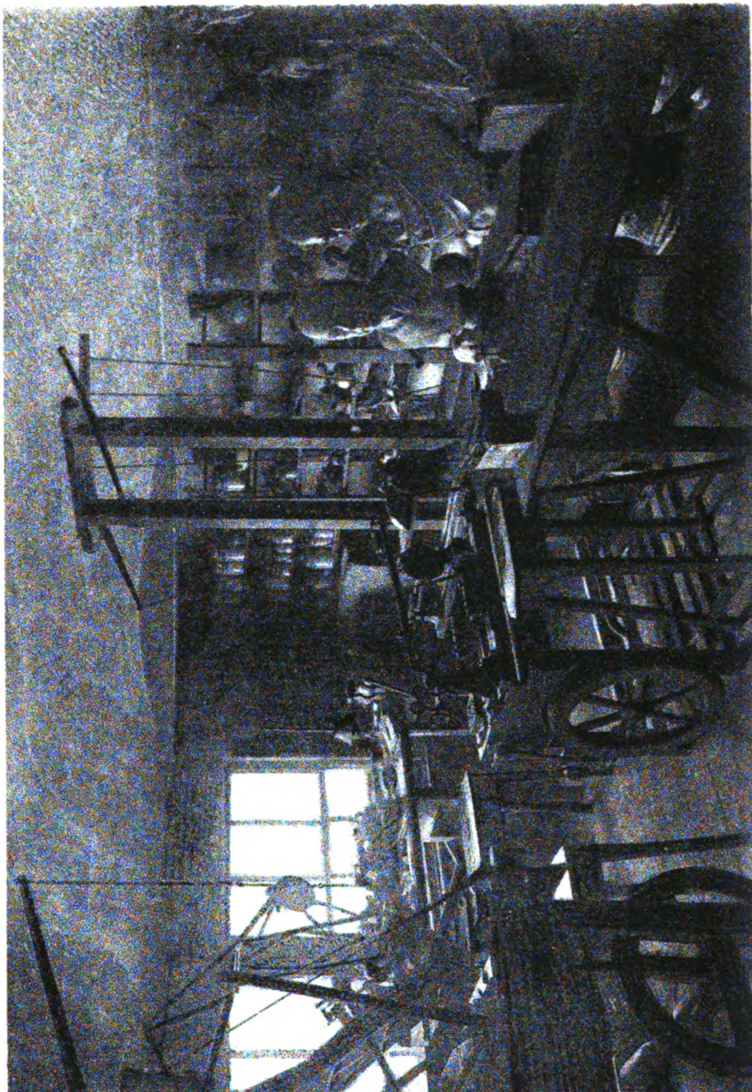
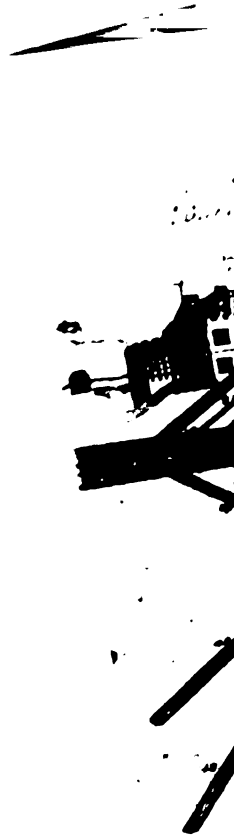


Fig. 57. Interior of Watt Room, Heathfield Hall.



R E F E R E N C

By Figures, to the several Member

1 The Fire Mouth under the Boyler with a Lid
2 The Boyler 5 Feet, 6 Inches Diameter, 6 Feet 1
4 Inches, Content near 13 Hogsheads.
3 The Neck or Throat betwixt the Boyler and th
4 A Brass Cylinder 7 Feet 10 Inches high,
Condense the Steam.
5 The Pipe which contains the Buoy, 4 Inche
6 The Master Pipe that Supplies all the Office
7 The Injecting Pipe fill'd by the Master Pipe
8 The Sinking Pipe, 4 Inches Diameter, that
9 A Replenishing Pipe to the Boyler as it
10 A Large Pipe with a Valve to carry the
11 The Regulator moved by the 2 Y y and
12 The Sliding Beam mov'd by the little
13 Scoggen and his Mate who work Double
14 The great Y that moves the little y a
15 The little y, guided by a Rod of Iron
16 The Injecting Hammer or F that move
17 Which Barge has a leaking Pipe, be
18 The Leaking Pipe 1 Inch Diameter,
19 A Sniffing Basin with a Cock, to fil
20 The Waste Pipe that carries off the
21 A Pipe which covers the Piston w
22 The Great Sommers that Support t
23 A Lead Cystern, 2 Feet square, fi
24 The Waste Pipe to that Cystern.
25 The Great Ballanc'd Beam that W
26 The Two Arches of the Great Ba
27 Two Wooden Frames to stop th
28 The Little Arch of the Great B
29 Two Chains fix'd to the Little
30 Stays to the great Arches of t
31 Strong Barrs of Iron which g
32 Large Pins of Iron going thr
33 Very strong Chains fixed to
34 Great Springs to stop the
35 The Stair-Case from Botton
36 The Ash-hole under the F
37 The Door-Case to the W
38 A Stair-Case from the Fi
39 The Gable-End the Gr
40 The Colepit-mouth 12
41 The dividing of the Pu
42 The Mouth of the Pu
43 The Pump-trunk withi
44 A Large Cystern of W
45 The Pump within the
46 The Floor over the W
47 The Great Door-Ca
48 Stays to the Great
49 The Wind to put
50 A Turn-Barrel over
51 The Gage-Pipe to
52 Two Cocks within
53 A little Bench wi
54 A Man going to R
55 The Pick, Ax and
56 The Centre of

Hirundo &c.

(*Proceeding*

Plate 87.

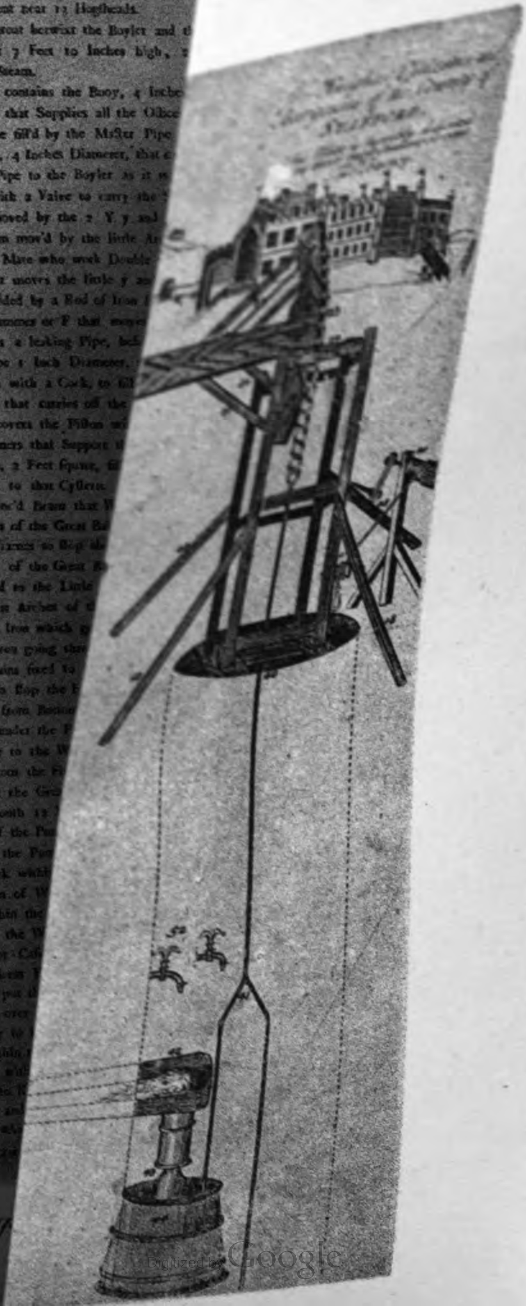
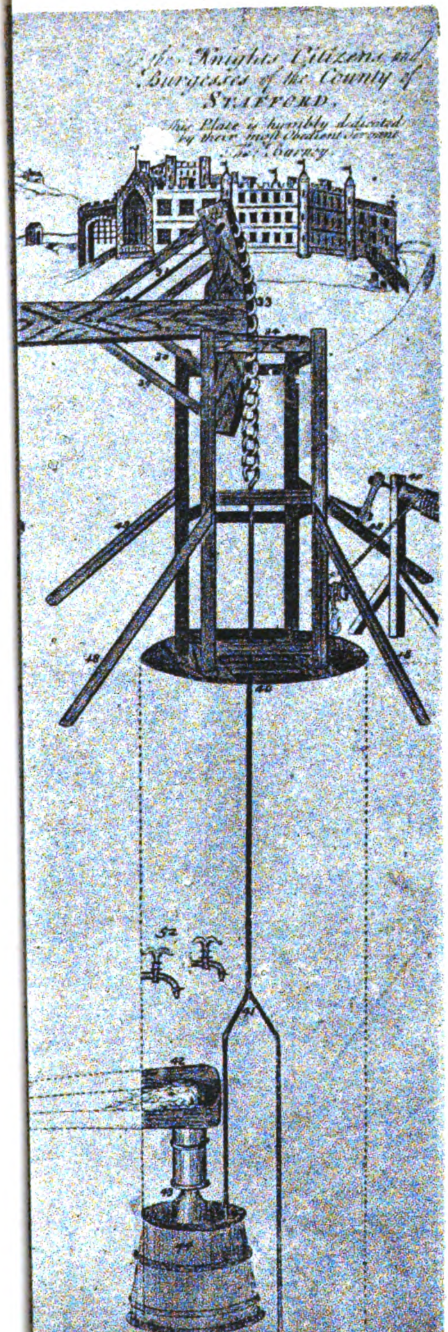


Plate 87.


Knights Citizens and
Burgesses of the County of
STAFFORD.
This Plate is humbly dedicated
by their most Obedient Servant

EXPERIMENTS ON FRICTION.

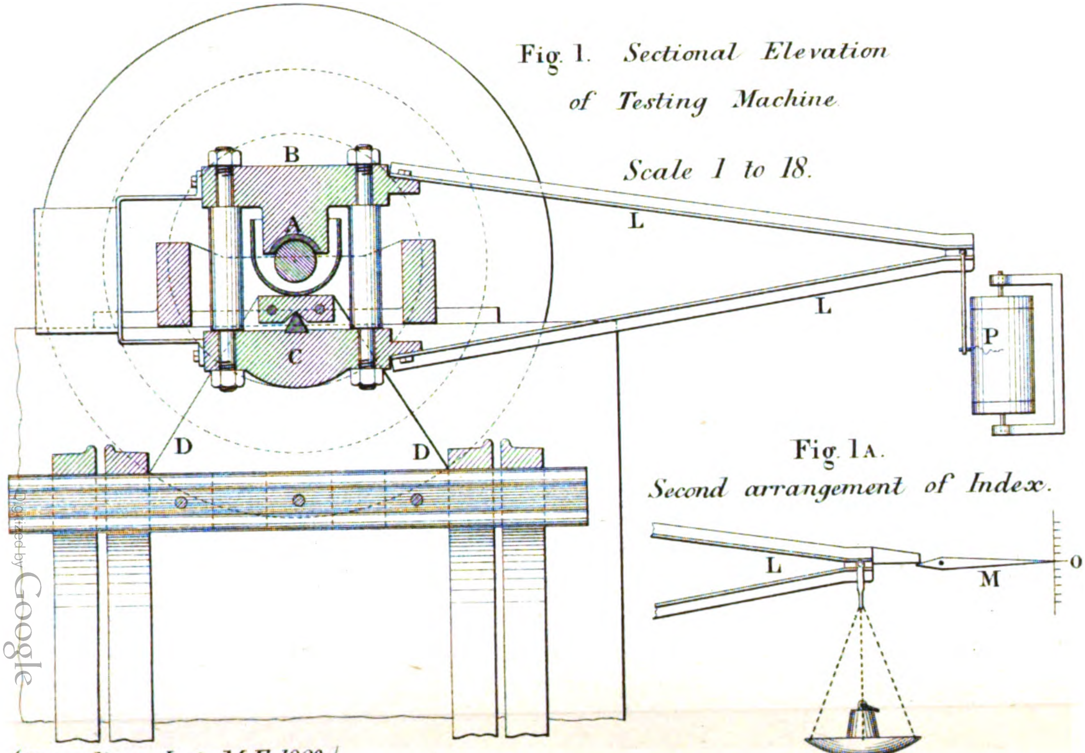


Fig. 1. *Sectional Elevation of Testing Machine*

Scale 1 to 18.

Fig. 1A. *Second arrangement of Index.*

Fig. 3.

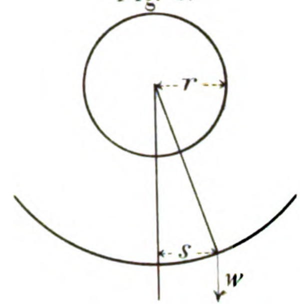


Fig. 4.

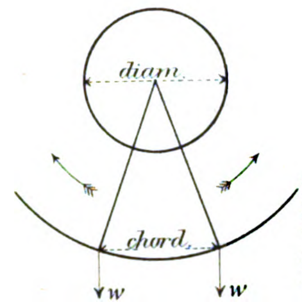


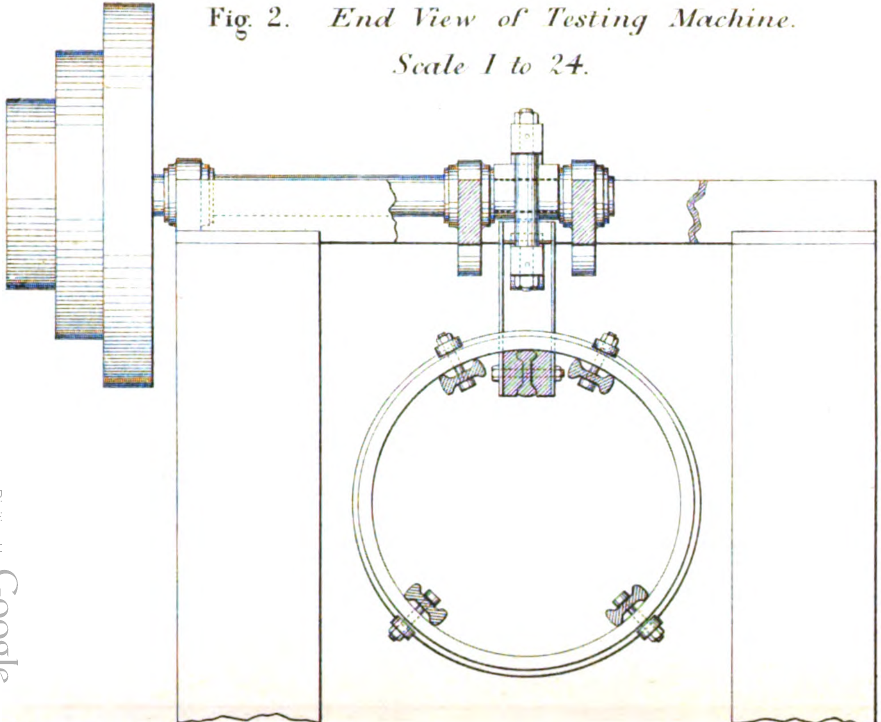
Plate 88.

EXPERIMENTS ON FRICTION.

Plate 89.

Fig. 2. *End View of Testing Machine.*

Scale 1 to 24.



Final arrangement for Lubrication.

Fig. 9.

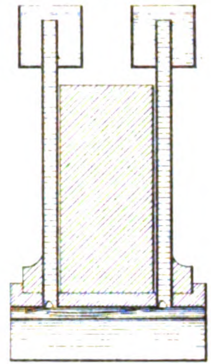


Fig. 10.

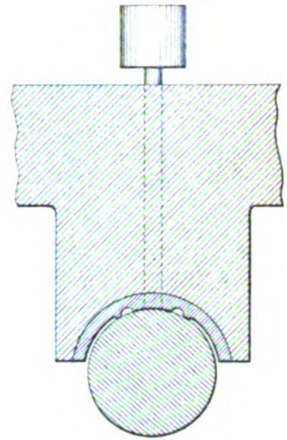
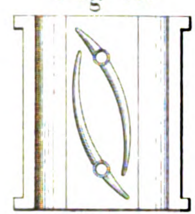


Fig. 11.



Scale 1 to 6.

Plate 89.

(Proceedings Inst. M. E. 1883.)

EXPERIMENTS ON FRICTION.

Arrangements for Ordinary Lubrication.

Fig. 5.

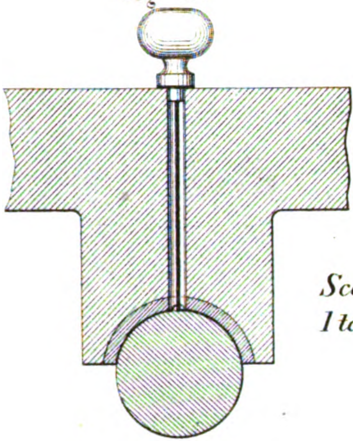


Fig. 6.

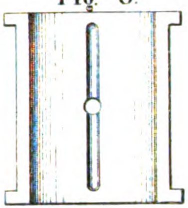


Fig. 7.

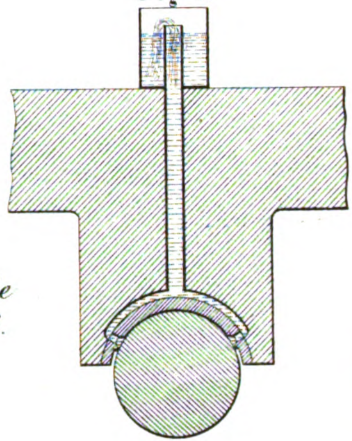
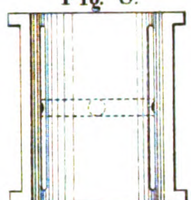
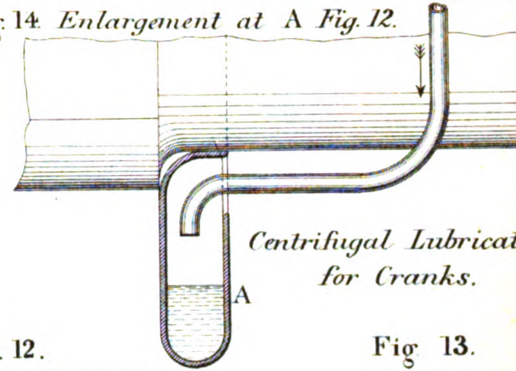


Fig. 8.



Scale 1 to 6.

Fig. 14. *Enlargement at A Fig. 12.*



Centrifugal Lubricator for Cranks.

Fig. 12.

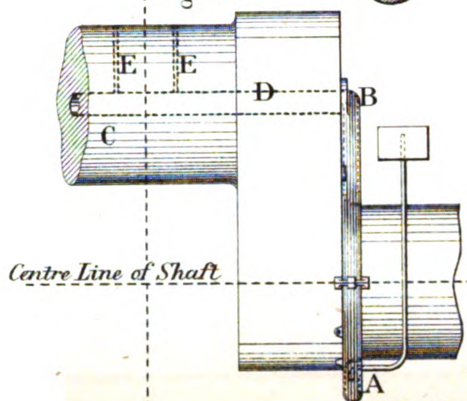
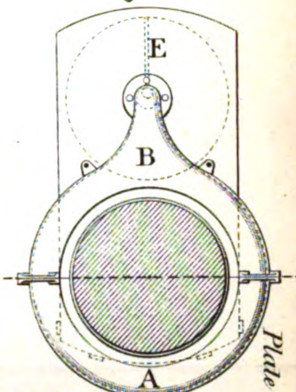


Fig. 13.



Scale 1 to 20.

Plate 90.

NAME	DATE
C. N. Cross	12/17/09.
R. L. Daugherty	6/10/10
B. M. Green	FEB 8 1915
F. SAPHRA	FEB 18 1950
J. N. Goodier	
N. Simms-SRI	1-20-56
~~IVOR K. McIVOR~~	~~JUL 16 1959~~
~~R. M. G.~~	~~JUL 10 '59~~